

METALLURGIA

THE BRITISH JOURNAL OF METALS

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SEPTEMBER, 1957

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METALLURGIA

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INCORPORATING THE METALLURGICAL ENGINEER

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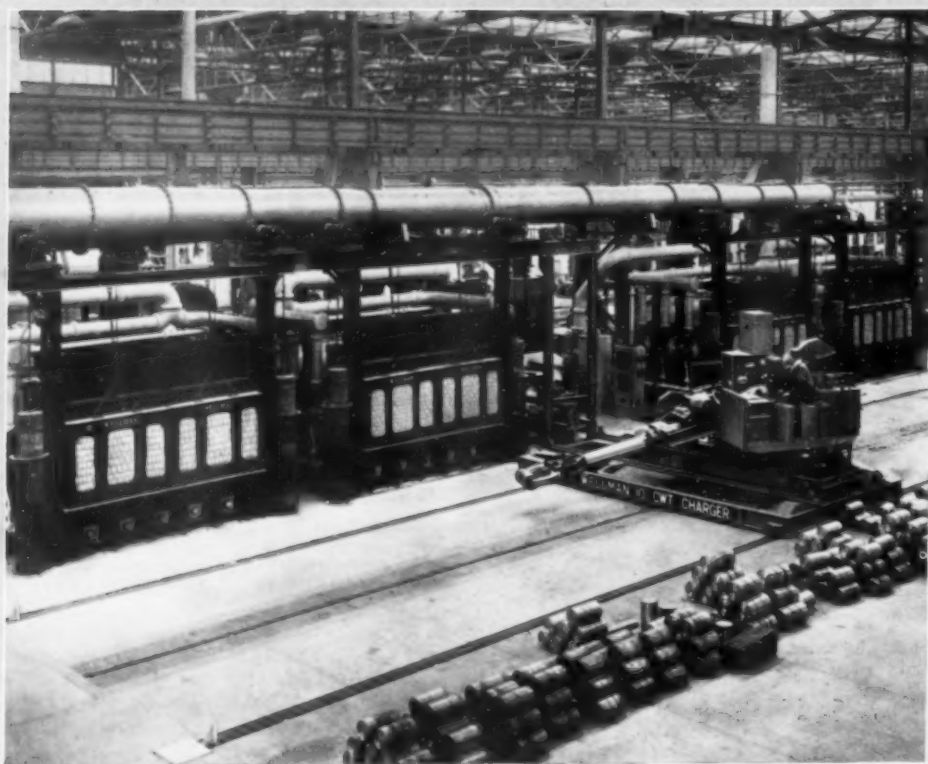
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METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

SEPTEMBER, 1957

Vol. LVI. No. 335

Coal—Present and Future

WITH the advent of nuclear power, the conversion of furnaces and power station boiler plant to oil firing, and the suggestion that coal—the last stronghold of the domestic rationing scheme—might be derationed, one may, perhaps, be forgiven for imagining that coal is no longer the important raw material that it was. A glance at the figures for 1956 will put the matter in proper perspective. In that year, 218 million tons of coal were consumed in this country for all purposes, 38 million tons of which were used in the home. The first figure represents 85% of the total energy used in sustaining the life of the nation and in maintaining the standard of living of the people. Far from it replacing coal in the next few years, it is generally thought that more than twenty years may elapse before nuclear power can supply a major proportion of the energy requirements of the country that are now met by coal, as distinct from filling the increasing gap between supply and demand; even then, if industrial activity increases at the expected rate, coal fuel may be required in considerable quantities for at least as long again. Oil, essential for some purposes, may make an important contribution to the interim fuel gap.

The need for a research and development programme into the use of coal as vigorous as that now undertaken in the atomic energy field was emphasised by the President of the British Coal Utilisation Research Association, Dr. W. Idris Jones, C.B.E. in his address at the Annual General Meeting of the Association reported in the recent *B.C.U.R.A. Quarterly Gazette* (No. 31). Dr. Jones pointed out that the Association's research activities fall into two fairly distinct categories: those concerned with present methods of coal utilisation; and those concerned with uses of coal likely to be of importance in future years.

The first category includes what may be regarded as short-term projects concerned with the present overall shortage of coal in relation to the limited extent to which consumers can be offered coals of their choice. The increasing use by the coal industry of mechanical methods of coal mining has resulted in the production of a higher proportion of small coal. In the past, large coal has been considered necessary for the satisfactory operation of certain types of plant and appliances, and it is significant that in 1956 the N.C.B. had to import about 3½ million tons of large coal to meet such demands, paid for mainly in dollars. There are two main lines of attack on this problem: (1) to develop ways of using small coal efficiently for all purposes; and (2) to design appliances in such a way that they are more flexible in the range of fuels that can be used without loss of efficiency. This is the basis of the Association's investigations into the performance of the mechanical firing equipment now used for steam-raising by industry, as well as improvements in design. It also provides the incentive for the work on domestic and central heating

appliances, as well as that on the cyclone system of combustion, which is concerned with the burning of fine high-ash coal.

Additional to the need for economy through efficiency in coal utilisation, and closely connected with it, are the requirements of the Clean Air Act of 1956. To implement this Act effectively, much improvement will have to be made in the equipment in which coal is burned, and in the methods of preparing coal for the market. Both industrial and domestic consumers, as well as the producers of fuel, have parts to play in attaining the clearer atmosphere envisaged by the Act, and can benefit from the scientific approach to coal utilisation that research embodies.

Helping to bridge the gap between suitable coal supplies and energy requirements and assisting the implementation of the Clean Air legislation have been major objects of the research work in B.C.U.R.A. during the year, and the Annual Report indicates the contributions made by those researches that are likely to find early industrial application in steam raising plant, gas producers, domestic heating, etc. The other class of research activities referred to earlier, namely, longer term researches, has not, however, been neglected, and progress has been made in studies of the chemical and physical nature of coal and its exploitation, a field in which the Association has justly gained an international reputation. Dr. Jones foresaw the possibilities of the basic research providing important future developments in the use of coal as a source of chemical products, which will be particularly important when the demands on coal as a fuel eventually diminish.

In the work on the chemical constitution of coal, increasing attention has been paid to organic chemical reactions: the phenolic nature of coal has been found to have an important influence on the ease of these reactions. Among newer techniques, one of considerable potential value is electrolytic reduction at a constant voltage in an organic solvent; this has already given valuable confirmation of the presence of quinone groups in coals, and provides means for their further study. An infra-red spectrometer of most recent design is being found of particular value in investigating small quantities of complex materials.

Other investigations in this category are calculated to meet the needs in future years of changing conditions, and include new methods of total gasification of inferior fuels at elevated temperatures and pressures. These, in turn, are opening up important projects relating to the behaviour of molten mineral matter under oxidising and reducing conditions.

It will be evident from the foregoing that, as befits a material which to-day is our major source of energy, and to-morrow may be an important source of chemical products, work aimed at improving existing methods and equipment is being carried on simultaneously with the fundamental research on which the future of coal depends.

Personal News

COL. D. G. N. LLOYD-LOWLES is the new Chairman of the Amber Group of Companies, of which he has been a Director for some time. He succeeds the late Mr. A. MORTIMER, who died in January of this year. Mr. J. CRONK is Managing Director. Mr. G. C. BAKER (the Group Secretary), has been appointed to the Board of Amber Chemical Industries, Ltd.

MR. G. S. WEBSTER has been placed in charge of the Stoke-on-Trent Sub-Office of the English Electric Co., where he will be responsible for the sale of all products.

SAMUEL FOX & CO., LTD., a subsidiary of the United Steel Cos., Ltd., announce that Mr. G. D. ILLINGWORTH has been appointed Labour Manager. He succeeds Mr. B. BUTCHER, who was recently appointed a Director of Samuel Fox.

FOXBORO-YOXALL, LTD. will shortly open their new factory at Redhill, Surrey. To ensure that full advantage is taken of the increased production facilities which will be available, the Company is now engaged in a re-organisation and expansion of the staff. First appointments to be announced are: Mr. B. W. BALLS to be Technical Sales Manager and Mr. A. H. ISAAC to be Manager of the Sales Engineering Department.

Two Special Directors recently appointed to the Board of Amber Oils, Ltd., are Mr. V. E. BAKER (as Commercial Director) and Mr. E. G. REYNOLDS (as Works Director).

THE following appointments to the Board of Vickers Armstrongs (Aircraft), Ltd., have been made: Mr. H. H. GARDNER, Mr. A. W. E. HOUGHTON, Mr. B. STEPHENSON and Mr. S. P. WOODLEY, M.B.E.

MR. M. G. KAUFMAN, President of Intra Continental Export Co., has joined Eastern Metal Converters, Inc., as Vice-President and Treasurer.

MR. W. A. HARTOP, Works Director of George Kent, Ltd., is at present on a four months Commonwealth tour which includes visits to Malaya, Australia, New Zealand and Canada.

AT a recent twentieth anniversary dinner party, Mr. V. D. MACLACHLAN, Sales Director and General Manager of Honeywell-Brown, Ltd., was presented with a "20-year pin" by Mr. O. B. WILSON, Vice-President of the Company's associates in Philadelphia.

MR. B. G. CHURCHER has relinquished his position as Manager of the Research Department of Metropolitan-Vickers Electrical Co., Ltd., but he will continue to act in an advisory capacity. He is succeeded by Dr. J. M. DODDS, O.B.E.

MR. G. B. PARTRIDGE, until recently Chief Metallurgist, Elektron Foundries, with the Birmingham Aluminium Casting (1903), Co., Ltd., Smethwick, has now joined William Mills, Ltd., Wednesbury, as Development Officer.

MR. P. J. C. BOVILL, J.P., Managing Director of Newton Chambers & Co., Ltd., Thorncliffe, near Sheffield, sailed on the *Ile de France* on August 16th for the United States of America, on a combined holiday and business trip.

NORTHERN ALUMINIUM CO., LTD., announce that Mr. C. J. BUCHANAN-DUNLOP, formerly of Birmingham Sales Office, has taken up the appointment of Manager of the Sales Administration Division, Banbury, and Mr. J. A.

AMBLER, formerly head of the Metallurgical Section of the Sales Development Division, takes charge of a newly-formed Market Research Section of the Sales Department, also with office in Banbury.

METROPOLITAN-VICKERS ELECTRICAL CO., LTD., announces the appointments of Mr. M. BIRD, Assistant Superintendent, Insulation Department, as Superintendent, Insulation Department and Bury Factory; Mr. D. B. JOHNSTON as Assistant Superintendent, Plant Department; and Mr. N. BRADSHAW as Assistant Superintendent, Foundries and Pattern Shop.

A NUMBER of new appointments are announced by Sparklets, Ltd., the Tottenham engineering firm. Mr. F. J. FAY has been appointed Metallurgical Chemist; Mr. N. V. GEDDES, Foundries Superintendent; Mr. F. W. BINKS, Trimming Shops Superintendent; Mr. E. H. AMIS, Superintendent of the Sparklets Syphon Section; Mr. J. H. COPE, Superintendent of the Product Finishing Section; and Mr. J. H. BRISTON, Chemist.

MR. R. H. BROWN has joined the research staff of the British Steel Castings Research Association as a Senior Investigator in the Plant Engineering Section. Mr. Brown was formerly Assistant to the Technical Manager of James Neill & Co. (Sheffield), Ltd.

MR. L. WEBSTER has been appointed Production Manager (Engineering) of Distington Engineering Co. Ltd., a subsidiary of The United Steel Cos., Ltd. Mr. C. SCOTT has been appointed Personnel Manager of the Company in succession to Mr. J. P. PEARSON, who is joining United Steel's Department of Operational Research and Cybernetics in Sheffield.

MR. J. F. HERBERT has been appointed to the newly-created post of Manager, Overseas Atomic Projects, with the English Electric Co., Ltd. He has also been elected a director of the English Electric Export & Trading Co.

Obituary

We regret to record the death of the following:—

MR. L. K. BRINDLEY, Consultant to the President of The International Nickel Co., of Canada, Ltd., who died on July 29th, after a brief illness. At the time of his retirement last February, Mr. Brindley was Deputy Chairman of the Mond Nickel Co., Ltd., which he joined in 1948, following his resignation from the Falconbridge Nickel Co., Ltd., of which he had been President. At the time of his death, Mr. Brindley was a Director of the Anglo Metal Co., Ltd., and Deputy Chairman of the Council of the Copper Development Association.

MR. W. C. KERRIGAN, Assistant to the President of the International Nickel Co. of Canada, Ltd., who died in New York on July 16th. Mr. Kerrigan joined International Nickel in 1930 as a member of the Sales Department, and in 1933 was made an Assistant Manager of the Nickel Sales Department, of which he became Manager in 1946. In 1952, Mr. Kerrigan was elected Vice-President and General Sales Manager of The International Nickel Co., Inc., responsible for both nickel and mill product sales.

MR. R. B. WHITE, Technical Representative of Armstrong Whitworth (Metal Industries), Ltd., and Jarrow Metal Industries, Ltd., in the Midlands Area, who died on July 31st.

Tool Steels for the Moulding of Plastics

By C. C. Hanson, A.I.M.

Chief Metallurgist, Radiation, Ltd.

While tremendous strides have been made in plastics technology over the past thirty years, there has been little change in the fundamental composition of the tool steels used in their moulding. However, because of increasing tool costs, much greater attention is being paid to the inherent quality and correct usage of these steels. In this article, these two important aspects are discussed together with the characteristics of the various steels available.

THE steels used in the making of moulds and dies for fabricating plastics are subjected in use to varied and arduous conditions. They have to be capable of withstanding the effect of long periods at temperatures up to, and sometimes above, 200° C. They should also have some measure of stain or corrosion resistance, and be able to resist the abrasive action of various moulding powders. In the following pages there are considered in greater detail the requirements of steels for use in this sphere of industry.

REQUIREMENTS OF A MOULD STEEL

Machinability

There are several methods available for constructing a die cavity, the three main ones being hobbing, machining, and piecing up in an outer case from separately machined sectional blocks.

The steels used for hobbled cavities should be relatively soft and plastic, with as low a rate of work-hardening as possible, so that the hobbing pressures and the stresses imposed upon the master hob are not excessive. The grain size of such a steel should be small so that a fine surface is obtained from the hob without the tendency for an orange-peel effect. Should the latter arise, then there is need for further, and often excessive, polishing operations, thereby defeating one of the advantages of the hobbing process. It is unfortunate that the finer the grain size of the hobbing steel, the greater the hobbing pressures required, due to the increased resistance to plastic deformation. It is necessary, therefore, to choose some intermediate condition which combines the plasticity of a coarse grain with the good surface finish of a fine grain, such a condition being shown in Fig. 1.

The resistance of a steel to taking a hobbled impression increases as its carbon content increases, and also as the alloy content increases. Consequently, low carbon mild steels are the most easily hobbled, but they do not give very good service owing to their not being amenable to hardening, other than by carburizing. To improve the hardening properties of the steel, alloy additions are made, notably nickel, chromium and molybdenum, but these cause a stiffening of the steel and need for more frequent inter-stage anneals during the hobbing process. It is obviously necessary that whatever type of steel be used for making a hobbled impression, it must be as soft as possible, with a Brinell hardness of less than 130, and preferably below 120.

The type of steel used for machining in the preparation of a die impression is very different from that used in hobbing. It is usually much more heavily alloyed and of a higher carbon content. These conditions make it much harder, even in the annealed condition, with a Brinell

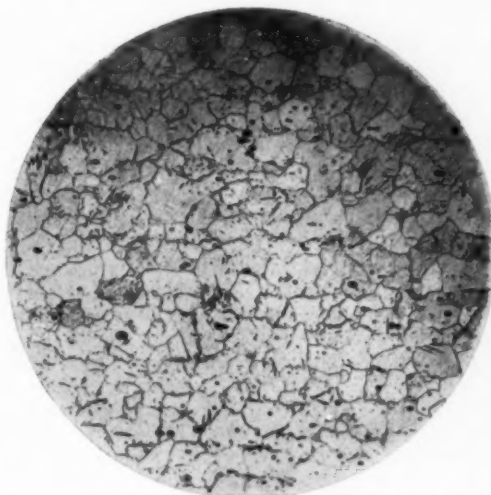


Fig. 1.—Photomicrograph showing grain size of low carbon steel (Type A) suitable for hobbing and subsequent case-hardening. × 100

hardness of between 150 and 260, the upper limit being quite common. With the higher hardness and, consequently, higher strength, the steel presents certain machining problems, although with slow speeds and light cuts, it can be fairly well managed on ordinary tool room equipment. The internal structure which the steel maker endeavours to achieve is known as spheroidized, and an example is shown in Fig. 2. In this condition, the steel is at its optimum machinability but at its lowest strength. Consequently, it should be borne in mind that from the aspect of strength and other physical properties a steel in the annealed or spheroidized condition is in its weakest state and should not be used in this condition for plastic moulds.

With many types of steel available for use in the plastics industry, it is small wonder that there are considerable variations in the ease of machining. Those steels which are high in chromium, molybdenum and tungsten have very hard carbides, and hence tend to wear away the cutting tools more rapidly than steels which are relatively free from them. This applies even in the annealed and spheroidized conditions. Steels containing nickel and manganese tend to be tough rather than hard, so that unless correct tool angles are used the machined surface is rather rough, containing fine tears at right angles to the direction of cutting. The importance of using correct tool angles when machining is often

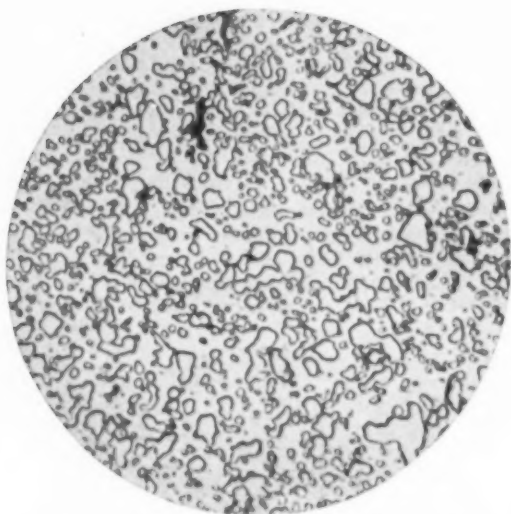


Fig. 2.—Photomicrograph showing spheroidized carbides in high carbon-manganese tool steel (Type F). $\times 350$

overlooked by tool makers, who frequently use one set of tool profiles for a whole range of steels, without due regard for the machining characteristics of their material. Unless the transverse tearing of the metal produced during heavy machining is removed by a light finishing operation, the cracks, which may extend to a considerable depth, can act as stress-raisers during heat treatment and grinding, with the possibility of subsequent failure. It is insufficient to leave a surface "rough-machined" just because it is not a part of the tool cavity or an important dimension. All surfaces may be subjected to similar stresses during heat treatment.

A further point to be borne in mind, still in connection with machining, is that in spite of a long annealing treatment tool steel bars and blocks may still contain some internal stresses. While the section remains whole, these stresses are in balance, but can easily be thrown out of balance when parts of the section are removed by machining, resulting in a "springing in" or "out." Further distortion can also occur when the finished tool is hardened, and to overcome the trouble it is advisable to divide the machining programme into two parts, viz.: roughing and finishing. Between these two operations a stress-relieving anneal is carried out at 600 to 650° C., for a length of time dependent upon the size of the block. The longer the time that can be allowed the better.

Heat Treatment Reliability

This feature is probably the most important consideration with mould steels. Through incorrect hardening and tempering processes the whole time expended on a mould can be wasted, and when one thinks in terms of moulds costing many hundreds of pounds, an injudicious attempt to save time or money at this stage is rather foolish. Unfortunately, in many instances, heat treatment is looked upon as a necessary evil, and the department is regarded as the "Cinderella" of the tool room where an attempt is made to catch up on a production schedule that has fallen behind during the machining stages.

As will be seen later, there are available today several types of plastic mould tool steel, all of which have been

extensively tried by the steel maker and tool maker. Consequently, if the quality of the steel is maintained and care is paid to design, difficulties need not be expected. To a large extent heat treatment is a matter of common sense. All steel suppliers provide pamphlets and books on their individual steels, listing the forging, annealing, hardening and tempering temperatures and conditions. While it is impossible to anticipate all the variations which are likely to arise throughout industry, none of the common plastic mould steels require "tricky" heat treatments, such as one encounters with chisel and riveting tool steels. The most that a hardener is called upon to do is to anneal for the removal of machining stresses, heat up slowly to the hardening temperature, soak for a period dependent upon the thickness of the tool sections and upon whether it is packed in spent charcoal, remove from the furnace and quench in oil or air (or both), and temper as soon as the tool has reached hand warmth.

The features which seriously affect movement in hardening of the steels under discussion are to be found in the design and construction of the moulds. Such things as unbalanced sections adjacent to each other, sharp corners, dowel holes in close proximity, and so forth, have been brought to the notice of tool designers and makers many times before, but instances of the cracking of moulds, either in heat treatment or after a short life, are still common, and they can in many cases be attributed to design. It cannot be emphasized too strongly that the designer must bear in mind the properties of the material he is employing. Hardened tool steels have a limited strength, and should the combined cooling stresses from the quenching treatment exceed it, cracking will occur.

In order to minimize the cracking and distortional effects of quenching, there has been developed the process known variously as "martempering," "hot quenching," "delayed quenching" or "interrupted quenching." With steel suitable for plastic moulds having relatively slow quenching rates, the process is easily applied and adds considerably to the safety of quenching irregularly proportioned moulds. It consists of quenching the steel from its normal hardening temperature in a bath of molten salt or lead alloy (usually the former) at a temperature of between 250 and 350° C., until it has cooled down to the temperature of the medium, then removing and allowing it to cool and harden in still air. By this means, the distortional stresses arising from cooling, as opposed to hardening, are considerably reduced.

Further troubles which can arise during hardening include: soft spots, scaling, oxidation, decarburization and burning of thin sections. Soft spots may be caused by irregularities in the steel (about which the hardener can do nothing), or by using cold tongs to withdraw the tool from the furnace. Where case-carburized tools are concerned, soft spots may be due to the previously mentioned reasons, or to unclean surfaces contaminated with such things as the copper from marking out, and apart from the first these are features of bad practice. Scaling and oxidation are often caused by similar conditions. They are due to an oxidising furnace atmosphere surrounding the tool being heat treated. Their prevention is fairly simple, and the methods available are the employment of some form of controlled atmosphere; packing in a protective medium such as spent charcoal; or heat treating in a salt bath. Such procedures pay in

the long run because of the lower mould finishing costs. Decarburization may also be prevented by these means. The burning of thin sections is in most cases due to placing a tool directly into a furnace running at too high a temperature. Such sections, with their lower thermal capacity, heat up rapidly and are held at heat too long, with a resultant deterioration of the steel.

Cleanliness

In addition to the danger of a dirty steel cracking during heat treatment, there is also the problem of the surface finish of the mould. Most moulds have the cavities polished to a greater or lesser degree, dependent upon the article they are producing, and also for ease of ejection or stripping. For transparent plastics of the polystyrene and methyl methacrylate types, an optical polish is often imperative. To this end, it is of the utmost importance that the steel be clean and free from segregated impurities. The term "dirty steel" is used to embrace a multitude of defects, from pipe to pin hole porosity. As well as the more obvious defects such as cracks, internal checks, etc., which are often shown up on rough machining, the finer defects which affect the surface finish of a mould are micro-porosity, oxide inclusions, sulphide and slag inclusions, and dendritic segregation. If any of these defects are present in objectionable amounts, then apart from plating to a fair thickness with nickel and chromium, or just plain chromium, there is little that can be done.

Micro-porosity, as the term implies, consists of very small cavities usually located at the grain boundaries of the steel. It is caused at the ingot stage by shrinkage or gas evolution and failure of the cavities to weld during forging; fortunately it is very rare in tool steels.

Oxide, sulphide and slag inclusions are regrettably much more common than porosity, and consist of particles of foreign matter distributed throughout the steel. They are due to faulty practice at the melting and casting stages, and cannot be corrected by any modification of the forging technique. An example of oxide inclusion is shown in Fig. 3. The way in which these inclusions contribute to the production of a poor surface

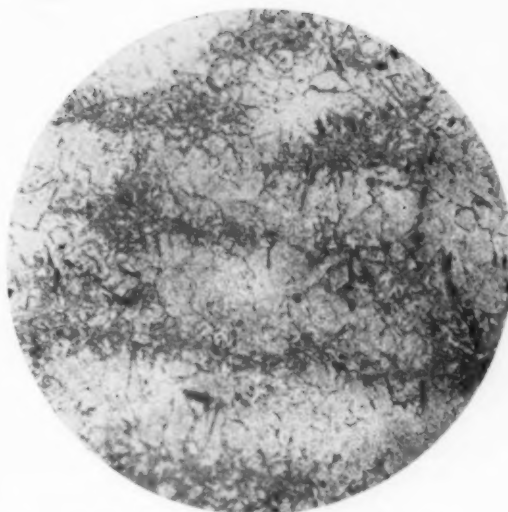


Fig. 4.—Photomicrograph showing dendritic structure in nickel-chromium-molybdenum steel (Type E) after hardening. $\times 50$

finish is fairly simple to understand. They are by nature rather brittle, and the degree of cohesion between themselves and the surrounding steel is relatively low, so that during grinding and polishing they are dragged out of the surface. This leaves a small cavity which fills up with the polishing compound and produces a characteristic "tailing" effect in the direction of rotation of the polishing head. In order to minimize this effect, it may be necessary to use the lightest polishing pressures and continually change the direction of polishing through 90° .

Dendritic segregation is, even to experienced technologists, a difficult thing to assess from the "trouble-shooting" point of view. The high alloy tool steels, particularly of the nickel-chromium-molybdenum type, are rather prone to it, and considerable attention is paid to the problem by the steel maker in order to keep it to a minimum. Its occurrence is due to the fundamental nature of the crystallization of metals on solidification in the ingot, and every effort is made to keep the as-cast grain size small, and to subject the ingot to as much reduction in forging as possible, so that the grain is adequately broken up without loss of consolidation. Should the segregation persist down to the finished bar, then it consists of small adjacent zones of varying chemical composition. As a consequence of this, there is a variation in the as-quenched hardness of the zones, with the result that they wear at different rates. This variation may show up in the initial polishing or later on, in use, as a characteristic pattern of slight depressions. This defect is shown in Fig. 4.

Another trouble, similar to dendritic segregation, but peculiar to the high carbon-high chromium steels, is that of carbide segregation. Owing to the high carbon content of this type of steel (1.5-2.5%), there is a considerable quantity of free carbides which are very hard. In fact, the steel owes its remarkable wear resistance to their presence. Here again, unless every effort is made to break up the "as cast" networks of carbides, they will persist as knots or stringers in the finished bar, and show up on polishing or in use. This feature is shown in Fig. 5.

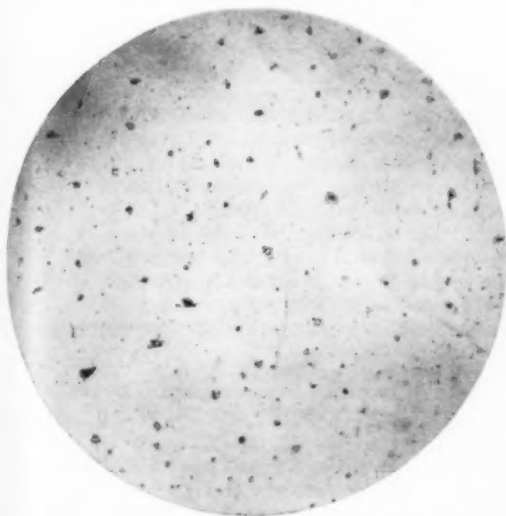


Fig. 3.—Photomicrograph showing oxide inclusions in "dirty" tool steel. $\times 100$



Fig. 5.—Photomicrograph showing stringers of chromium carbide in high carbon-high chromium tool steel (Type I). $\times 100$

Resistance to Deformation and Wear

Before discussing this property or requirement of mould steels, a few words on hardness and wear-resistance are necessary. While these two properties of a material are closely allied, they are by no means the same. Most hardness tests consist of forcing, under constant load, either a hardened steel ball or a diamond into the material, and then measuring one or more dimensions of the impression produced. The impression obtained embraces, in the terms of the microstructure of the material, a considerable area. Now a number of steels contain, when hardened, either tungsten or chromium carbides embedded in a matrix of martensite. The individual hardness of these carbides may or may not be greater than that of the martensite matrix, but more often it is, and the hardness test itself only reveals the hardness of the aggregate. Further, the carbides have a considerable abrasion resistance. Therefore, it is possible to have a water quenched plain carbon steel, with a Rockwell hardness of C67, with a lower wear resistance than an air hardened 2% C-12% Cr steel with a hardness of only Rockwell C60. Consequently, when assessing the wear resistance of a given steel, other factors arise besides hardness, and the hardest steel is not necessarily the one which is going to give the longest service.

The hardness value of the mould does indicate what tensile and compressive strength we can expect from the steel, and it is a good guide to the efficiency of heat treatment. The strength of the steel employed in mould construction is something which is ignored by many mould designers. Experience of previous mould failures due to cracking in use encourages the increase of various sections to guard against a repetition of failures, but there is little or no attempt to work from the first principles of "strength of materials" engineering.

Let us consider a very widely used steel, namely the 4½% nickel-chromium-molybdenum material. The Rockwell hardness of this steel in the hardened and tempered condition will range from C45-53, or an

equivalent tensile strength of 94-119 tons/sq. in. The tensile strength is the actual breaking stress, the stress at which the first displacement occurs being much lower, at about 80 tons/sq. in. Couple this with the cyclic and hence fatigue nature of the stresses imposed during moulding, and it will be seen that the continuous working strength of the steel is not what it might at first have been assumed. In fact, tests have shown that the endurance or fatigue limit of a tool steel is between 30% and 40% of its static tensile strength, or, in this particular case, between 35 and 45 tons/sq. in. Such weakening factors as notch effects and surface finish have been ignored in this assessment.

The resistance to deformation by indentation is of course directly related to the hardness of the steel, and as many of the working loads on a mould, such as closing pressures, injection pressures, etc., are of this type, hardness checking is a useful safeguard and guide from this aspect alone, irrespective of others.

The advantages of some of the shallow hardening tool steels for plastic moulds have been stated on several occasions. The hard skin and tough core have been particularly recommended with statements to the effect that the case provides wear resistance and the core resistance to sinking. The first part is probably true, but how a soft centre prevents sinking is a little difficult to comprehend, particularly when the applied stresses are compressional. One may liken the effect to the cracking of concrete when laid upon unconsolidated ground, and in the writer's opinion the most useful field of application for this type of steel is in dowel pins, etc.

The property of wear resistance is a very critical one in the life of some parts of plastic moulds, particularly those used in injection moulding, where there is a considerable movement of the plastic. Of the steels discussed later, the high carbon-high chromium steel and those suitable for nitriding provide the greatest wear resistance and are used for torpedo spreaders and gates, etc. Hard chromium plating is also used with a good measure of success.

Reference has already been made to the subject of cracking, particularly that resulting during heat treatment. A form of cracking which has not yet been discussed is fine surface cracking. This is due to thermal fatigue from the expansional and contractional effects of alternate heating and cooling. It may or may not have its origin in the grinding operation, during which minute surface cracks of some 0.002 in. depth can be formed. It can also occur where high local pressures arise, as at the lands and closing faces. Apart from what has already been said on heat treatment, thermal fatigue can be minimized by using a tough steel, and by giving a really long tempering of 6-10 hours. It must be remembered that the operating temperatures of moulds often approach the tempering temperature of the steel, so that unless a good tempering has been given, physical and structural changes occur during operation—a most undesirable feature.

Resistance to Staining and Corrosion

With the continuous developments in plastic materials, the stain resistance of mould steels to the plastic ingredients has become more important. The common element which contributes this property to a steel is chromium, other elements conferring similar properties being far too expensive for normal use.

While chromium confers stain resistance, all steels

TABLE I.—HOBGING AND CARBURIZING GRADES OF PLASTIC MOULD STEELS.

Reference	Nominal Chemical Composition (%)						Heat Treatment Temperatures (° C.)					Quenching Medium	Hardness Number	
	C	Mn	Si	Ni	Cr	Mo	Anneal	Carburize	Refine	Harden	Temper		As-Annealed (Brinell)	As-Hardened (Rockwell "C")
A	0.05	0.2	0.1	—	—	—	600-650	900-925	880-900	790-800	150-250	Brine	100	58-64
B	0.1	0.45	0.25	1.25	0.6	—	600-650	900-925	880-900	790-810	150-250	Oil	120	58-64
C	0.1	0.45	0.25	3.5	1.5	—	600-650	900-925	880-900	760-780	175-275	Air or oil	150	55-62
D	0.1	0.3	0.25	—	5.0	1.0	600-650	—	—	940-960	200-400	Air	125	50-55

containing it do not necessarily possess this property. For effectiveness in this sphere, the steel should contain approximately 12% or more of chromium. The two main steels finding application in this respect are the low carbon—12% chromium hobbing steel, and the 0.3–0.6% carbon—12% chromium die steel, which is virtually the standard stainless cutlery steel. The very common 2% carbon—12% chromium steels are not quite up to the standard of the two just mentioned, but are satisfactory for normal purposes. The well known 18% chromium—8% nickel austenitic stainless steel finds little application because it cannot be hardened by heat treatment. Even the high chromium steels are not always satisfactory against some of the cellulose acetate plastics, and it is necessary to use phosphor bronze or other non-ferrous materials to overcome the difficulty.

A useful workshop test to check stain resistance of tool steels is to clean the surface free from scale, etc., degrease it with a solvent such as carbon tetrachloride or trichlorethylene, and put a drop of vinegar or a drop of 33% nitric acid upon the clean polished surface. As the vinegar dries the concentration of acetic acid in it increases. The nitric acid may be removed after ten minutes or so, but the interval adopted must always be the same to give comparative results. Stain resistance is assessed by comparing the intensity of attack at each of the spots.

It should always be borne in mind that a stainless steel does not develop its maximum stain resistance until it has been hardened and polished. In the annealed condition the metal is often susceptible to corrosion and staining.

MOULD STEELS AND THEIR CHARACTERISTICS

Hobbing and Carburizing Grades

The steels used for hobbing may be self hardening, or they may require carburizing to render them suitable for use. Further, both types of steel can be made up into moulds by machining or by part machining and hob finishing. Compositions and details of appropriate heat treatments are given in Table I. The choice of a particular steel is, of course, dependent on many features. Steels A, B and C require carburizing in order to develop surface hardness, but when heat treated, steel C gives quite a high core strength (in the range of 60–80 tons/sq. in. tensile) providing substantial backing for the case.

Steel D is of a different type from the others, and there are several variations of it available. It is direct harden-

ing after forming or hobbing, and is as hard as other tool steels which cannot be hobbled.

Oil and Air Hardening Grades

These are by far the most common steels used in plastic mould engineering. Compositions and heat treatment details are given in Table II.

Steel E, a nickel-chromium-molybdenum type, is very similar to B.S. 970: En30B, and may be considered within the 100 tons/sq. in. tensile group. It is used in considerable quantities in this country and on the continent of Europe, but hardly at all in America. After heat treatment, it is characterized by a moderate hardness and wear resistance, but considerable toughness, because of its low carbon content. As far as heat treatment is concerned, either air or oil hardening can be used, depending upon the size of the mould or component, but, because of the possibility of pitting, care should be exercised in the use of salt baths for heating. The steel is quite amenable to martempering, with its improved safety in hardening. The two main drawbacks to this steel are its low machinability and its susceptibility to dendritic segregation. This latter defect is shown in Fig. 4, and can best be overcome by giving a long anneal at 820° C. to facilitate diffusion of the alloy elements, because its presence increases the risk of cracking.

Steel F, known as the carbon-manganese type, is the principal one used in America for plastic moulds, while in this country it has a high reputation for press tools. Like steel E, it is non-distorting and hardens from a low temperature, although it has not the depth of hardening of the other steels in this series. The chief drawback to this and other high hardness steels is a lack of toughness, which, in addition to the high as-quenched and tempered hardness, can render them susceptible to thermal fatigue under the repetitive cycle of moulding. Provided the steel is clean it will take a high polish.

Steel G, the intermediate between F and I, is non-distorting and resists abrasion. Although it is available in this country, it is not used very much, being more favoured in America.

Steel H is the air hardening counterpart of steel I, and owing to its lower carbon content is more tough. It has extremely good wear resistance and non-distorting properties, and by tempering at 500° C. a considerable increase in toughness can be obtained with only a slight sacrifice of wear resistance.

Although not easily machined, a greater disadvantage with both steels H and I is the possibility of stringers of

TABLE II.—OIL AND AIR HARDENING GRADES OF PLASTIC MOULD STEELS.

Reference	Nominal Chemical Composition (%)						Heat Treatment Temperatures (° C.)			Quenching Medium	Hardness Number	
	C	Mn	Ni	Cr	Mo	V	Anneal	Harden	Temper		As-Annealed (Brinell)	As-Hardened (Rockwell "C")
E	0.33	0.4	4.0	1.3	0.25	—	600-650	820-850	200-600	Air or oil	250	35-55
F	0.9	1.5	—	0.4	—	0.2	750-780	780-800	150-300	Oil	220	58-65
G	1.0	0.4	—	5.0	1.0	0.3	830-850	940-980	200-400	Air	220	58-62
H	1.5	0.3	—	12.0	1.0	0.75	870-900	1000-1020	200-550	Air	230	55-62
I	2.1	0.3	—	12.0	—	0.4	840-860	950-980	200-400	Oil	230	58-63
J	0.3	0.3	—	12.0	—	—	870-900	1000-1030	150-250	Oil	230	50-55
K	0.6	0.4	1.75	1.0	0.5	—	600-650	840-870	200-250	Oil	250	58-60

TABLE III.—COMPARISON OF PROPERTIES AND PRICES OF PLASTIC MOULD STEELS.

Reference	Wear Resistance	Toughness	Depth of Hardening	Risk of Distortion	Machinability (1% C Steel = 100)	Stain Resistance	Hardness (Final)	Relative Price Index
A	High*	High	Shallow	Medium	130	Low	High	50
B	High*	High	Shallow	Low	100	Low	High	65
C	High*	High	Shallow	Very low	85	Low	High	75
D	Medium	High	Medium	Very low	90	Medium	Medium	200
E	Medium	High	Deep	Very low	70	Medium	Medium	150
F	High	Medium	Medium	Low	85-90	Low	High	150
G	High	Medium	Deep	Very low	75-80	Medium	High	270
H	High	Low	Deep	Very low	45	High	High	280
I	Very high	Low	Deep	Very low	40	High	High	280
J	Medium	High	Medium	Low	75-80	Very high	Medium	250
K	Medium	High	Deep	Low	75	Low	Medium-high	150

* After carburizing.

hard chromium carbides showing up on polishing or in use. Finely ground surfaces do not exhibit this trouble, but any attempt at optical finishes may be unsuccessful. An important application of this type of steel is in the making of master hobs where its high compressive strength gives it a superior performance.

Steel *I*, the other high carbon-high chromium type in this series, probably has the highest wear resistance of any of the tool steels except high speed steel. It is oil hardening, has excellent non-distorting properties and, like its fellow *H*, is moderately stain resisting because of the high chromium content. It has the same drawbacks as steel *H*, but it is very good for master hobs, gates and torpedo spreaders in injection moulding machines, because of its resistance to wear and tempering.

Steel *J* is used only for special applications where stain resistance is required, e.g., in moulding optical components and certain plastics which are chemically active, such as ureaformaldehyde and some of the acetates. This steel is almost identical with the conventional high chromium cutlery steels used for knives, etc., and it will be seen from Table III that its hardness and wear resistance are not high.

Steel *K* is a low alloy hob steel which, because of its

rather low carbon content has an element of toughness lacking in the high carbon-high chromium types. Although slightly lower in hardness, it has sufficient compressive strength to meet the requirements of hobs for mild steel, etc.

In Table III is given a comparison of the physical and other properties of the steels listed in Tables I and II. Comparisons of this type are difficult to make, but such a guide can be of help in deciding between two steels for a particular application.

It must not be thought that the steels listed here are the only ones used for plastic moulds. There are several variations of the steels discussed, the makers claiming the improvement of certain properties arising from the addition of other alloying elements. Such claims as cleanliness and homogeneity may be justified, but in a given composition group there is not a great deal to choose between the variations. It is the consistency of quality which is of importance to the mould maker.

Other steels in use include silver steel, common hardening, ground flat stock and mild steel plate, but they are not used in the same quantities as those previously discussed, and do not have as much time spent on them, being used mainly in ancillary equipment.

Industrial Potential of Titanium

TITANIUM, the metal developed primarily for defence needs, will have numerous additional uses in civilian industry within five years, according to Dr. R. L. CARMICHAEL, metals economist at Battelle Institute. Writing on the "Industrial Potential of Titanium" in the *Battelle Technical Review*, Dr. Carmichael points out that the price of the metal is steadily being reduced, and that within five years titanium sheet, rods, and bars should sell at one-third to one-half of current prices. At such prices the metal, because of its superior properties, will be economic for many uses in the chemical and process industries and in certain consumer products.

In commenting on specific non-military uses for the metal, Dr. Carmichael estimates from 50 to 100 different applications have already been made in prototype products. Examples include the use of the metal in:

- (1) The engine cowling and firewall of commercial planes. (The DC-7 uses about 400 pounds finished weight; the DC-8 will probably use twice as much.)
- (2) Impellers, packing-support grids, heat-exchangers, filter presses, condensers, jet diffusers, vessel liners, coils, valves, and agitator covers in the chemical industry.
- (3) Kettles and other equipment for processing acid foods, such as tomatoes, pickles, and sauces.

(4) Liners for reactors and mixers in pulp and paper processing.

(5) Clips and racks in aluminium anodizing shops; agitators, tubing, and valves in metal refining.

(6) Valves and trim for marine equipment.

(7) Anodes, heater bottoms, grid contact rings, and cathode rings in miniature electronic tubes; wires in rectifiers.

(8) Prosthetic devices for orthopedic surgery; hypodermic needles; braces and crutches.

Most applications of the metal have resulted from the desire to take advantage of its good corrosion resistance, its high strength-to-weight ratio, and its good abrasion resistance. Being extremely resistant to many corrosive solvents, it does not contaminate materials coming into contact with it, which is vitally important in certain chemical processes.

Shortcomings in using the metal at present are the high cost; poor resistance to certain powerful reducing agents; lack of availability in certain forms; difficulty in welding certain alloys; the problem of galling, which is preventable; and high scrap loss due to the inexperience of fabricators. Most of these shortcomings, the Battelle metals economist states, should be overcome as research continues and as users of titanium gain experience with it.

The Production of Zinc in a Blast Furnace*

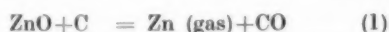
By S. W. K. Morgan, A.R.S.M., B.Sc.

A process developed by the Imperial Smelting Corporation, Ltd., for smelting zinc in a blast furnace is now being used for the production of 70 tons per day at Avonmouth. The furnace gases, which typically contain 5-6% zinc and 8-10% carbon dioxide, are brought into contact with a shower of molten lead, whereby 89% of the zinc vapour is condensed and recovered as metal. The process can be applied to mixed lead-zinc concentrates, the lead being tapped from the bottom of the furnace.

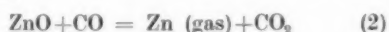
THE problem of smelting zinc in a blast furnace has been studied by the Imperial Smelting Corporation at Avonmouth for the past twenty-five years. The problem presented many difficulties; some of these could be foreseen, and our first efforts were directed towards elucidating the physical chemistry of the reactions involved. By 1939, these preliminary studies had reached the point at which the erection of a pilot-scale furnace was being considered. Naturally, very little work could be done on the project during the war years, but afterwards experiments were continued. Although difficulties were encountered, the furnace trials showed that the process was essentially sound. Not only was it found possible to obtain zinc from high-grade zinc ores, but later work has established that mixed lead-zinc ores can be treated to yield directly both zinc and lead as metals. There are now two furnaces in operation at Avonmouth, producing between them 70 tons of zinc per day and varying quantities of lead, depending on the nature of the charge.

Zinc Smelting Processes

The characteristics of pyrometallurgical problems of zinc smelting are governed by the facts that zinc oxide is reducible with difficulty and zinc metal is volatile. At atmospheric pressure, zinc oxide can be reduced by carbon only above the boiling point of zinc. Most of the world's zinc is produced in either small horizontal or large vertical retorts, in which the essential reaction is:—



This reaction between two solids proceeds in two stages:—



At the temperature (950° C. upwards) at which the gases are generated in the retort, the equilibria in both reactions (2) and (3) are such that the ratio of carbon to carbon monoxide is small. Therefore, the gas produced contains but little carbon dioxide—less than 1%—and since the only oxygen available for combining with carbon is that originally combined as zinc oxide, the gas, as shown by equation (1), consists essentially of equal volumes of zinc vapour and carbon monoxide, from which the zinc is condensed by cooling.

The equilibrium in reaction (2) becomes still more displaced to the left as the temperature is lowered. Consequently, as the gases are cooled for condensation, there is some tendency for even the small amount of carbon dioxide present to oxidise the zinc vapour.

The overall reaction (1) is the sum of two strongly endothermic reactions (2) and (3). Therefore, in retort smelting a large amount of heat has to be supplied through the retort walls, and the amount of zinc that can be smelted per unit area of retort wall is limited. Consequently, for a long time, all zinc was produced in small batch-operated horizontal retorts, and it was only in 1929 that the New Jersey Zinc Company overcame a number of major difficulties and developed the first continuous distillation process in large vertical retorts constructed of silicon-carbide bricks; this represented a very big advance, but the output from each of the largest retorts yet built is only 8-9 tons per day.

Thus, while all the other major metals were being produced from large blast furnaces or reverberatory furnaces, zinc was still being produced in relatively small units. The volatility of zinc precluded its being tapped direct from a furnace, like the other metals. In the types of furnaces used for most metals, the heat required for the reduction reactions is provided by fuel which is burnt in contact with the charge. To produce zinc metal from such furnaces, it would be necessary to condense the zinc from its mixture with a large volume of combustion gases, and this for long constituted an insuperable difficulty. Consequently, while abortive attempts were made to produce zinc from a blast furnace, the first successful attempts to circumvent the size limitations of retort smelting followed other lines.

The first successful process for producing a gas of essentially the same composition as from retorts, but in a large furnace, was the electrothermic method, using the electrical resistance of the charge to supply the heat required, developed by the St. Joseph Lead Company in 1931. In this process, a single unit produces 50 tons of zinc metal per day; the charge is preheated and, with a condenser of special design, the process works continuously with a high condensation efficiency.

Before the development of the New Jersey and St. Joseph processes, an entirely new method had been developed in the electrolytic process, in which zinc is deposited on aluminium cathodes from purified zinc sulphate solution. This process, first successfully operated in 1916 at Anaconda, Trail and Risdon, is now widely adopted, particularly where power is cheap and plentiful. The rate of growth of the electrolytic process can be gauged from the fact that in 1953, 38% of the world consumption of primary zinc was produced by the electrolytic process and 62% by the retort processes. In spite of the rapid expansion of the electrolytic method, it can be seen that the greater part of the world's zinc is still made by retort smelting.

All retort processes suffer to some extent from the fact that the considerable amount of heat required to carry

* Acknowledgment is made to the Institution of Mining and Metallurgy, to whom this paper was presented and in whose *Transactions* it first appeared.

out the reduction of zinc oxide must be forced through a refractory wall. The St. Joseph process overcomes this difficulty by heating the charge electrically. In the horizontal retort process, the maximum size of retort in common use is one with a capacity of some 2 cu. ft., producing from 50 to 70 lb. of metallic zinc per 24 hours. A modern horizontal furnace will contain as many as 500 of these retorts, each of which has to be charged and discharged separately. Even the New Jersey process does not overcome the disadvantage held by all retort processes—that indirect heating must be employed and a production battery must be built up of a number of small separate units.

Direct Smelting to Liquid Zinc

Although the volatility of zinc introduces complications into its metallurgy, compared with other metals, yet from one point of view it gives zinc an advantage over other metals reduced only with difficulty, such as manganese, by making it possible to effect a clear-cut separation from the more reducible non-volatile metals, particularly iron, with which it is associated in its ores. It would be thermodynamically possible to reduce zinc oxide directly to liquid zinc under pressure but, even if such a process could be operated, it would be pointless, because all the iron present would be reduced and only a zinc-iron alloy; requiring a redistillation to separate the zinc metal, would be obtained. The efforts made in the past to operate zinc blast furnaces under pressure so as to prevent the zinc being volatilised were all unsuccessful; what does not seem always to have been realised is that their objective was a mistaken one.

Basis of Early Work at Avonmouth

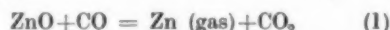
The urge to develop a blast furnace process arose from the hope of developing large units, with relatively low capital and operating costs. The further prospect was envisaged of not being restricted, like retort processes, to treating high-grade concentrates of low iron content, but of being able to treat low-grade mixed concentrates to effect the simultaneous recovery of other metals present, such as lead, silver and copper.

With respect to fuel economy, the advantages of the blast furnace for zinc were initially not as clear. In all types of condensers known before 1943, it had been possible to condense zinc only from gases substantially free from carbon dioxide. If this limitation were accepted, all the heat required would have to be provided by burning carbon to carbon monoxide, thus utilising only a fraction of the calorific value of the carbon, so that this would require a high ratio of carbon to zinc oxide in the furnace charge, even if some of the gas were subsequently burnt to provide heat for preheating the air blast and the charge. Under these conditions, such a furnace could operate with a high thermal efficiency only in so far as it could be regarded as being primarily both a gas producer and a zinc producer. A study of the problem showed that the zinc blast furnace could be thermally efficient in its own right, only if the gas generated contained a considerable amount of carbon dioxide. The primary problem to be solved was recognised to be that of condensing zinc from a gas containing a relatively low concentration of zinc vapour and a considerable amount of carbon dioxide.

Initial Experimental Work at Avonmouth

The guiding considerations in the first experiments at Avonmouth were that a ferruginous slag was to be run

off from the furnace, and, therefore, the gas initially generated there would initially contain some carbon dioxide; the zinc oxide would be reduced by the reaction:—



and therefore the final gas produced would contain more carbon dioxide than zinc vapour. Reaction (1) is reversible, and fall of temperature moves the equilibrium towards the left-hand side of the equation. Consequently, it was realised that special precautions would have to be taken to avoid oxidation of zinc vapour by carbon dioxide at all stages from its generation in the furnace to its condensation:—

- (1) To avoid re-oxidation of zinc within the furnace, the whole furnace charge must be maintained above the zinc re-oxidation temperature.
- (2) To avoid re-oxidation during the passage from furnace to condenser, the gases must not fall below their re-oxidation temperature¹.
- (3) To avoid re-oxidation in the condenser, the gases must be rapidly cooled².

The first point was met by a design in which a shaft was fed with a mixture of preheated coke and sintered zinc concentrates, with air blast introduced at both top and bottom, and the gases withdrawn at a middle level³. To meet the second requirement, the gases passed from the furnace through a column of coke heated electrically¹. A very small furnace was constructed on these lines; the scale was such that continual withdrawal of slag was not possible, so that a limited quantity of charge was treated in campaigns of up to 12 hours' duration.

This unit yielded a gas containing 2–3% zinc vapour and 6–8% carbon dioxide. In the first tests the gases were shock chilled by being led through narrow water-cooled tubes to produce zinc dust, which was carried forward and collected in filter bags⁴. The fact that this zinc dust contained 98% metallic zinc proved that the means adopted had been adequate to prevent oxidation of zinc vapour before it reached the water-cooled tubes. The next problem was to replace these water-cooled tubes by some form of condenser that would produce liquid zinc.

The key to the development of a successful condenser was the discovery that the use of liquid lead as a circulating medium for heat transfer and collection of zinc enabled oxidation of zinc vapour to be minimised⁵. Liquid lead, even when containing 2–3% zinc, could be pumped and handled with ease, so that the way was opened to the use of a number of devices such as are familiar in the scrubbing of gases by liquids. Particularly promising results were obtained by passing the furnace gas into a chamber containing a pool of liquid lead, which was showered into the gas by the action of a rotating fluted roller. Cooling the lead leaving the condenser caused separation of liquid zinc; pumping the lead in a circuit, made up of the condenser chamber, an external cooler, and a zinc separation bath, provided a method of continuous removal of both heat and zinc from the furnace gases and continuous separation of the zinc as a liquid layer above a liquid lead bath⁶.

From experience on the very small furnace first used, it was possible to proceed to the design of a small continuously operating shaft furnace.

Development of the Experimental Zinc Blast Furnace

The furnace on which the process was further developed consisted of a shaft 2 ft. 3 in. \times 3 ft. 6 in. with a charge column 10 ft. high, fed with coke and sinter-roasted zinc concentrates, both of which could be preheated, and blown at top and bottom with preheated air. The gas was withdrawn at a mid-level into a column of electrically heated coke, and thence into a condenser with a succession of stages in which showering of liquid lead was maintained by rotating fluted rollers. Lead was pumped countercurrent to the gas stream in the condenser and, outside the condenser, through a cooler and zinc separation bath.

Operation of this experimental plant led to many changes, of both design and procedure, from the initial conceptions. Some of these changes have been simplifications. It has been found possible to operate without the gas conditioning coke column and to condense the zinc from gas produced by blowing the furnace only from tuyeres at the bottom. Thus, the shaft furnace can be operated in a manner more nearly approaching the conventional blast furnace operation, with, however, the top of the furnace at a temperature of about 1,000° C. There were naturally problems both of construction and of operation in preventing excessive deposition of accretion of zinc oxide in the top of the furnace and in the flues bearing gas to the condenser; a number of ways were found of solving this problem, among which may be mentioned the burning of sufficient air in the gas to maintain its temperature above the re-oxidation point during its passage to the condenser.

Further development of the condenser led to a design of showering unit with vertical shafts projecting through the roof, through which they could be removed and replaced during a short shutdown of the furnace. The form of rotor finally evolved was of a robust design and gave a reasonably distributed copious showering of lead^{6,7}. A compact lead-cooling circuit was achieved by the use of water cooling, either of the walls of launders⁸, or of immersion coolers⁹; the heat-removal duty of this system is very substantial.

On this experimental plant the treatment of roasted zinc concentrates was studied in detail. Following this work the extension of the process to other types of charge was explored. The smelting of charges containing both zinc and lead values was a problem which had already arisen in connection with the treatment of zinc concentrates, since the dross and blue powder produced in the condenser, using liquid lead as a scrubbing medium was a mixed zinc-lead material, and its return to the smelting charge resulted in an appreciable lead feed to the furnace. Increasing the lead content of the charge, by treatment of lead-zinc ores or of mixtures of lead and zinc concentrates, involves new problems in condensation and in the handling of the products, now including bullion and matte as well as slag, from the furnace bottom¹⁰. These problems were solved and a situation attained in which the simultaneous smelting of lead imposed no additional burden on the zinc smelting operation. The discovery was made that allocation of coke for smelting the charge could be estimated from the requirements of zinc elimination and slag melting, no extra coke being required for the lead to be treated; the elimination of zinc and the efficiency of condensation was as high as in the treatment of roasted zinc con-

centrates¹¹. The explanation for this surprising feature of lead-zinc smelting was that with lead oxide present in the gas could be achieved without increasing the zinc content of the slag. The bullion produced collected the silver content of the charge and a substantial portion of the antimony.

The treatment of low grade charges was also studied, particularly zinciferous lead blast furnace slags and types of low grade zinc or mixed lead-zinc ores¹¹. These types of material were successfully smelted to yield metallic zinc.

Description of Present Units

Two pilot production furnaces were built at Avonmouth, one with a nominal capacity of 20 tons of zinc output per day, the other of 25 tons per day. The design of these units was undertaken at a relatively early stage in the development of the small experimental furnace, and modifications of the units have followed the major changes in experimental development. As a result, the furnaces now have capacities of 30 and 40 tons per day, respectively; in some aspects of design and in some of the service arrangements, the plant suffers from restrictions arising from the early stage of the project at which the design was laid down. Between them, however, these furnaces have produced more than 70,000 tons of zinc.

The furnaces have a water-jacketed bottom section, with water-cooled tuyeres, and a brick-lined top shaft. The smaller furnace has 16 tuyeres and a hearth area of 55 sq. ft.; the larger, 20 tuyeres and an area of 69 sq. ft. The tapped slag is granulated; with the development of zinc-lead smelting, arrangements for collection of matte and bullion in an external settler have been added. The hot zinc-containing gases are withdrawn above the furnace charge; the furnace top is totally enclosed, batch charges being introduced via a double bell system.

The gas from each furnace passes to two condensers, one on each side of the furnace. In each condenser there are three vertical shaft rotors in series, dipping in successive stages of the lead pool in the bottom of the condenser. The rotor creates an intense shower of lead droplets, which cools the gas to a temperature near that of the lead. By disposing the rotors in successive stages, with an appropriate lead flow countercurrent to the gas stream, the gases leaving the furnace are rapidly chilled below 600° C., and further cooled to about 450° C. before they leave the condenser. The uncondensed zinc leaving the condenser in the gas is thereby reduced to below 5% of the total entering the condenser.

The gas is further scrubbed, first in a spray tower, then in Theissen type disintegrators; the scrubbed gas (calorific value 70–80 B.Th.U./cu. ft.) is used on the plant to preheat air and charge, and the surplus burned in boilers. The water from spray towers and disintegrators passes to a Dorr thickener to recover the blue powder, which is filtered before return to the sinter machine charge.

In each condenser lead is pumped at a rate of 300–400 tons per hour round a circuit comprising the condenser, a pump chamber, a long water-cooled launder, and a separation bath. Control of heat removal is effected by varying the area of water-cooled surface immersed in the lead, and adjustment of temperature differential between the hot and cold ends of the con-

denser by alteration of lead pumping rate. The launders cool the lead stream to about 450° C.; cooling is completed in the separation bath in which the liquid zinc separates as a top liquid layer. By suitable disposition of overflow levels for zinc and lead, a zinc layer approximately 15 in. deep is maintained on the bath, and this zinc overflows continuously into a bath for reheating, and for treatment with sodium to remove arsenic. The cold lead returns continuously to the condenser.

The zinc produced is of G.O.B. or Prime Western Grade, and assays as follows:—

Pb%	Fe%	Cd%	As%
1.2	0.024	0.07	0.001

Slag, matte and bullion are periodically tapped from the furnace, the matte and bullion being retained in an external settler, and the slag passing on to a granulating system. The slag composition varies somewhat with the type of gangue in the concentrates treated. Its zinc content may range between 1% and 5%, but with close control of charge composition and proportioning, steady running with a zinc content of 2–3% can be consistently maintained. The lead content of the slag is about 0.5%, depending mainly on the efficiency of separation in the forehearth.

The air blast is heated in alloy tube recuperators fired with scrubbed furnace gas; the heaters installed at present allow a maximum preheat of 550° C. The charge is heated in a vertical shaft with a countercurrent stream of burnt furnace gas; automatic control arrangements ensure provision of a neutral mixture of gas and air, with sufficient recycle of the gas leaving the charge preheater to prevent overheating and slagging at the base.

The process lends itself to instrumental and automatic control, and this aspect has been exploited. The furnace is operated at constant controlled blowing rate, and the gas leaving the furnace is split between the two condensers by automatic damper control. The firing of air heaters is automatically controlled to fixed air temperature, and of charge heaters to provide neutral gas at a fixed inlet temperature.

Theory of the Process

Considering first the elimination of zinc from the furnace charge, the amount of zinc produced per unit of carbon burned is governed by the heat balance. The input of heat is the sum of:—

- the heat of combustion of carbon partly to carbon monoxide, partly to carbon dioxide, and
- the sensible heat of preheated air and preheated charge.

The heat is consumed in:—

- slag melting,
- heat losses,
- sensible heat of gases leaving the furnace (at a temperature not greatly removed from the equilibrium condition for the reaction $\text{CO} + \text{ZnO} = \text{CO}_2 + \text{Zn}$),
- endothermic reduction of zinc oxide by carbon monoxide, and
- reduction of carbon dioxide: $\text{CO}_2 + \text{C} = 2\text{CO}$.

A heat balance drawn up in this way clearly depends markedly upon the actual level of carbon dioxide in the furnace gas achieved in the operation; the higher the

percentage carbon dioxide, the more zinc oxide can be reduced per unit of carbon. The level of carbon dioxide is dependent upon a complex of conditions, including the temperature of the primary combustion zone, the depth and temperature of the charge column, the reactivity of coke (in reducing carbon dioxide) and of the zinciferous charge (producing carbon dioxide). A typical operation yields gas leaving the charge containing 5–6% zinc vapour, 8–10% carbon dioxide; such gas has an equilibrium re-oxidation temperature of 960–1,000° C.

The heat balance, and thus the amount of zinc eliminated per unit of carbon, is obviously influenced by the heat content of the air blast and by the actual magnitude of heat losses to water-cooled tuyeres and jackets. If extra heat is made available by raising air preheat, or by measures to reduce heat losses, the ratio of zinc to coke in the charge can be increased; if the zinc/coke ratio is kept constant, some of the extra heat is utilised in reducing the zinc content of the slag, but most of it is absorbed in reducing carbon dioxide.

Decreasing the amount of zinc left in the slag by increasing the coke/zinc ratio (and thereby increasing the ratio of carbon monoxide to carbon dioxide) is undesirable, not only because it reduces the zinc throughput, but also because the furnace gases must not be made so reducing that high-melting metallic iron is formed at the bottom of the furnace.

On the other hand, particularly if much arsenic is present, it is desirable that the CO/CO_2 ratio in the hearth zone of the furnace should approach that at which metallic iron is reduced, so that an iron-rich speiss (with a high thermodynamic activity of iron and a low activity of arsenic) can be formed. Since the thermal economy of the furnace is improved by decreasing the CO/CO_2 ratio, requirements are best met if the slag composition is such that its iron oxide activity is high and the activity coefficient of zinc oxide is high.

Rather poor zinc elimination is obtained with the type of slags generally used in lead smelting, but a low zinc content of slag is obtained by increasing the lime content; the lime can be added either at the furnace or in the charge to the sinter machine. Good zinc elimination is further favoured by the use of a reactive and porous sinter, and by ensuring an even charge distribution in the furnace.

The ratio of fuel burnt to zinc volatilised therefore depends on a number of factors, such as the temperatures to which the air blast and the charge are preheated, the heat loss from the furnace, and the amount of slag-forming materials present. On a typical furnace, with charge preheated to 800° C., and air blast to 600° C., the carbon consumption may be calculated as the sum of 90% of the weight of zinc to be volatilised, and 20% of the weight of slag to be formed. With a high grade mixed zinc-lead concentrate, in which the weight of slag formed may be 70% of the weight of zinc present, this means that the carbon consumed might be about 104% of the weight of zinc reduced and volatilised.

The coke consumption of the blast furnace is greater than the producer coal used in the best vertical retort practice, but less than the total coal consumption in producers and in briquette charge to the retorts. The reasons why the coke consumption in the blast furnace is greater than the nominal fuel consumption in the vertical retorts are: firstly, the carbon monoxide formed by the retort reaction is utilised as a fuel for

the retorts; secondly, a large amount of sensible heat is removed from the blast furnace gases in the condenser; and thirdly, there is still obtained an excess of blast furnace gas, the calorific value of which represents about 25% of that of the coke burned.

In condensing the zinc content of the furnace gas the primary object is to prevent the re-oxidation reaction, $\text{CO}_2 + \text{Zn} = \text{CO} + \text{ZnO}$, by shock chilling. Rapid cooling tends to promote fog formation but the seriousness of this aspect is lessened by:—

- (a) the high superheat of the gases, which have a dew point of about 650° C. and leave the furnace at 900°–1,000° C.,
- (b) the presence of a rain of unsaturated lead in which droplets of zinc are formed, but are themselves scrubbed by the intense rain of lead.

In condensing a gas containing 5% zinc, by counter-current scrubbing with cold liquid lead saturated with zinc, the quantities of heat and zinc are such that the lead becomes unsaturated, as it becomes hotter. A typical situation would be:—

Cold Lead ..	440° C., 2.02% zinc (saturated).
Hot Gas ..	5% zinc, 1,000° C. to be cooled to 450° C.
Hot Lead ..	570° C.

The quantity of lead required by the heat balance is such that it rises only 0.24% in zinc content and leaves, therefore, containing 2.26% zinc, compared with a saturation value of 4.9% zinc. Lead has to be circulated at a very high rate $100/0.24=420$ times the rate of zinc production, in order to maintain this situation.

Under favourable conditions, about 89% of the zinc vapour entering the condenser is condensed and recovered as molten metal. The remaining 11% of the zinc vapour is recovered in the dross periodically removed from the condenser, and in the blue powder washed out of the condenser exhaust gases. Both the dross and blue powder contain lead. Typically, the blue powder contains 32% zinc and 45% lead, and the dross 43% zinc and 36% lead.

The efficiency of the condenser is adversely affected by dust or fume carried over in the gases¹².

The reduction of lead oxide by carbon monoxide is slightly exothermic and, since this is in fact the reaction by which lead oxide is reduced in the furnace, the lead content of the furnace charge makes no demand upon the carbon, which is calculated in terms of the zinc to be eliminated and the slag to be melted. This feature of the process whereby lead is a "passenger" has been confirmed in the smelting of many zinc-lead charges. This effect is gained at the expense of a higher carbon dioxide content of the gas, but satisfactory condensation can still be attained. The condenser gas with high lead charges may contain 11–12% carbon dioxide, with 17–19% carbon monoxide, its calorific value being thus only about 60 B.Th.U./cu. ft. It is still more than sufficient for preheating the charge and air blast; about half the total gas produced is available for other uses.

Most of the arsenic present in the charge can be tapped as a speiss from the furnace, but some of it is volatilised and collected with the zinc metal, from which it can be removed by treatment with sodium¹³. When lead is being tapped from the furnace, it collects nearly all the antimony; any volatilised antimony that is collected with the zinc metal is removed by the sodium treatment. When sufficient sulphur is present, a matte is tapped from the furnace hearth.

Field of Application of the Process

The process provides a method for treating a variety of zinc-bearing materials to yield metallic zinc. As a blast furnace process it is not subject to the limitations on unit size of the retort processes; the larger unit at Avonmouth producing 40 tons of zinc per day is judged to be decidedly smaller than the optimum. The desirable size of furnace is envisaged at the present stage of the development as burning 90–100 tons of carbon per day. The associated air heaters, charge heaters, condensers and gas scrubbing system are all on a scale such as to yield decided economies in the capital cost per unit of smelting capacity.

The requirements of the process as regards raw materials are similar to those of other blast furnace operations. The fuel used is coke, typically of 3 in. lump size. The zinciferous materials are desirably also fed in lumpy form free from fines, and this has been achieved, in the cases examined so far, by sintering. From the nature of the process, with a hot furnace top and with gases then passing through a condenser, it is clear that good quality charge, free from fines and hard enough to prevent excessive breakdown in the furnace, is called for. Fluxing materials can be incorporated in the sinter (silica in the sinter can perform the dual function of strengthening the sinter and providing the necessary fluxing in the furnace) or added separately. The dross and blue powder are also incorporated with the sinter.

The process can be applied to high-grade zinc concentrates, but is not restricted to this type of material. The impurities brought in with the raw materials are rejected as a slag composed mainly of iron oxide, lime, silica, and alumina, and there is some flexibility in the choice of a target composition appropriate to any given ore. A lower grade of ore thus normally involves merely the melting of an additional load of slag, of acceptable composition, with a moderate effect on the coke requirement per unit of zinc.

While retort processes or electrolytic extraction methods experience such difficulties with materials very high in iron content as to prohibit their use, in the blast furnace process such materials can be smelted with ease. In retorts, the reduction of iron oxide by carbon to produce metallic iron is a highly endothermic reaction, the heat requirement for which is obtained at the expense of a lower zinc output; in the blast furnace the iron oxide is not reduced. The possibility of working with a self-fluxing mixture of ores or concentrates can also be attractive.

The process is particularly useful for smelting mixed lead-zinc concentrates, and has thus opened up the possibility of recovering directly both zinc and lead as metals from those lead-zinc ores in which the components cannot be completely separated by froth flotation. Even if the concentrates contain, besides galena and blende, a considerable amount of pyrites, the sinter-roasted material can be treated in the blast furnace without an unduly high fuel consumption.

The lead content of the raw material is obtained as lead bullion; this position contrasts with that of other zinc processes, where at best a lead-rich material for separate treatment is produced, and normally the lead enters a residue.

As in the conventional lead blast furnace, any silver present is collected almost completely in the lead metal, together with other metals such as antimony. Copper

present in small amounts can conveniently be collected with the lead. When any considerable amount of copper is present, the copper is tapped as a matte; this applies whether lead is being tapped or not.

Some volatile impurities are, however, more troublesome in this process than in retort processes. In particular, appreciable quantities of arsenic are volatilised, so that the zinc metal separating from lead at 450° C. contains typically 0.05% arsenic, which is removed by treatment with metallic sodium.

In addition to the patents referred to in the text and enumerated below, there are other patents and patent applications covering various aspects of the process and modifications of them. Corresponding patents and patent applications exist in numerous foreign countries.

Acknowledgments

A project of this magnitude could not be carried through without the full co-operation of a number of people. Thanks are due to the Directors for their support at all stages of a complicated and expensive operation, and for permission to publish this paper.

The Research and Development Departments at Avonmouth have been deeply involved throughout under the author's direction. Dr. S. E. Woods has been in direct charge of this work, and Mr. L. J. Derham has worked on the project from its earliest stages; many of the inventive ideas are due to him.

Mr. B. G. Perry has been responsible for the engineering design and construction of the plant, and Mr. W. R. Robertson for the operation of the commercial units since their construction. Dr. G. K. Williams has been associated as consultant with the project since 1948, and Mr. J. Lumsden has developed a number of theoretical aspects of the process.

Tribute should also be paid to Mr. Stanley Robson who provided much of the initial inspiration.

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| 4 British Patent No. 576,906. | 10 British Patent No. 741,243. |
| 5 British Patent No. 686,542. | 11 British Patent No. 741,249. |
| 6 British Patent No. 686,585. | 12 British Patent No. 759,709. |
| | 13 British Patent No. 744,408. |

Developments in Argonarc Spot Welding

FOR a number of years, the Argonarc spot welding process has made possible a joint between certain light gauge materials from one side only. A disadvantage of the process in the past, however, was that it proved inconsistent in operation and resulted in surface cratering and cracking of the fused zone. To prevent this, the weld metal must be cooled slowly, and British Oxygen have now introduced a system of control which effectively eliminates cratering, and gives consistent results. A D.C. rectifier is used as a power source, and crater control is effected by the introduction of resistances into the magnetic amplifier control circuit. The crater device reduces the current to zero in four stages.

The equipment used consists of the D.C. power source, timing control, and a torch which is normally held in the hand and is used to position the electrode above the

material and supply the argon which shields the weld. A trigger switch incorporated in the gun handle sets in motion the timing circuit, and the arc can then be struck for a pre-determined time. The heat from the arc flows over the interface and the fusion of the materials is completed.

The improved process is expected to be of particular value in view of the advent of higher speed aircraft. Higher skin temperatures necessitate the use of stainless steels as the structural material. The use of the Argonarc spot welding process for joining these materials means that rivets need not be used, and considerable weight-saving is effected. A sound joint without the addition of filler metals is achieved which has a high strength value. The process is applicable to the 18/8 group of stainless steels as well as some new high-tensile stainless steels, including FV 520 and FSM1.

In the work that has been carried out to eliminate the disadvantages of the process, British Oxygen have endeavoured to achieve maximum possible strength with all spot welds, together with a high degree of consistency. To ensure that each spot weld would be metallurgically sound, they have carried out a complete development programme on the 18/8 stainless steels, and this has proved highly satisfactory.

Kent Continental S.A.

THREE years ago, George Kent, Ltd., decided to establish a Branch Office in Belgium, originally with a staff of two. Since then the volume of business in the territory has so risen that the staff has been increased to eight and, in April, 1957, the organization in Belgium was converted into a separate company under the title of Kent Continental S.A. This new company, which has its headquarters at 82 Chaussée de Charleroi, Brussels, comprises a sales, engineering and service organization covering the full range of Kent products, fully staffed by Kent-trained engineers. In addition, there is a well equipped workshop, and a comprehensive stock of spare parts.



The improved Argonarc spot welding set up, with a system of current control to eliminate surface cratering and cracking.

The Physical Properties of Electrodeposited Metals

By T. E. Such, B.Sc.*

The second part of this article is devoted to a consideration of the methods available for the determination of tensile strength, ductility, hardness and internal stress in electrodeposited metals.

(Continued from page 66 of the August issue)

DETERMINATION OF PHYSICAL PROPERTIES

Tensile Strength

THE determination of the tensile strength of massive metals calls for comparatively simple techniques. It is not easy to apply these techniques to plated coatings because their thinness gives rise to practical difficulties. The usual method employed is to plate a thick (0.010-0.020 in.) deposit of the metal, as a sheet of this thickness can be handled much more easily than material of the order of 0.001 in. thick. The cathode used can be either stainless steel or some other metal to which the plate will not adhere. Some metal which can be dissolved by a reagent which does not attack the plate itself can also be employed as the basis. In both cases a fairly thick sheet of the material is available, which can be either stamped or milled, while being held in supporting blocks, into the conventional shape of a tensile test-piece. With brittle deposits, such as bright nickel, it is necessary to build up the ends of the tensile test-piece with soft nickel or copper so that the test-piece may be gripped in the testing apparatus without its ends breaking.

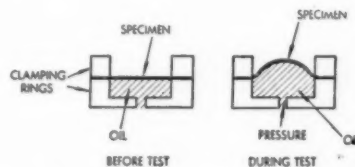


Fig. 5.—Hydraulic bulge test (Prater and Read).

Extremely brittle and hard deposits are difficult to machine, and it is best to plate these in the correct shape of a tensile test-piece by using a suitable jig with stainless steel as the cathode. Brenner, in his work on chromium, tackled this problem in a different way.¹⁹ He plated this metal onto copper tubes, which he subsequently dissolved away. Grips were provided by inserting a closely fitting steel rod into the end of the chromium tube and "cold-welding" the tube and rod by plating copper over both, while the centre of the tube was stopped off. The specimen was then held in the tensile testing machine by pins passed through holes in the end of the steel rod.

All such tests as those described are performed on much thicker deposits than are normally applied for decorative and protective purposes, due to the troubles encountered when attempting to deal with these thin foils. However, the tensile strength and, indeed, all the physical properties of electrodeposits are markedly affected by their thickness. The initial layers of a plated coating are usually more fine-grained than subsequent layers, and so the tensile strength of a very thin coating will normally be greater than a thicker one, taking into account the different areas of cross-section. This is illustrated by the graph showing how the tensile strength figures for Watts dull nickel deposits decrease as the coating thickness rises (Fig. 4).

Prater and Read, recognising this difficulty, have published a method²⁵ for determining the tensile strength of electrodeposited foils as thin as 0.2 in. To do this, they make use of the hydraulic bulge test. The principle of this is simple, and is illustrated in the diagram (Fig. 5). The specimen is a disc of the deposit to be tested which has either been stripped from a passive metal or had its base dissolved away. The disc is clamped between two rings and oil under pressure applied to one side. The pressure in the oil is increased and the specimen bulges until it fractures. The tensile strength can be calculated from the pressure at the moment of fracture and the height of the dome. It is claimed that this method is simple to use and specimen preparation

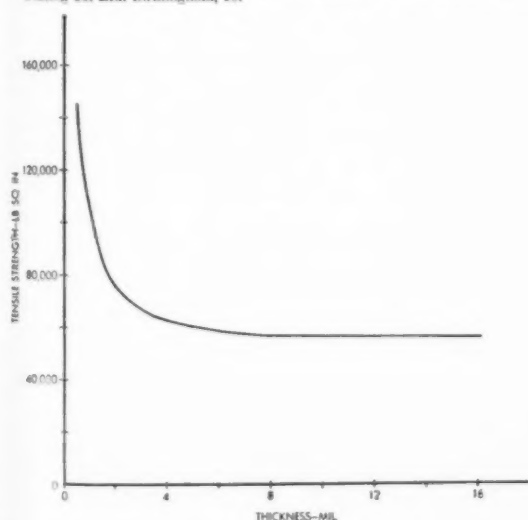


Fig. 4.—Variation of tensile strength with thickness of nickel coating deposited from a Watts dull nickel solution (Brenner, Zentner and Jennings) [1 mil. = 0.001 in.]

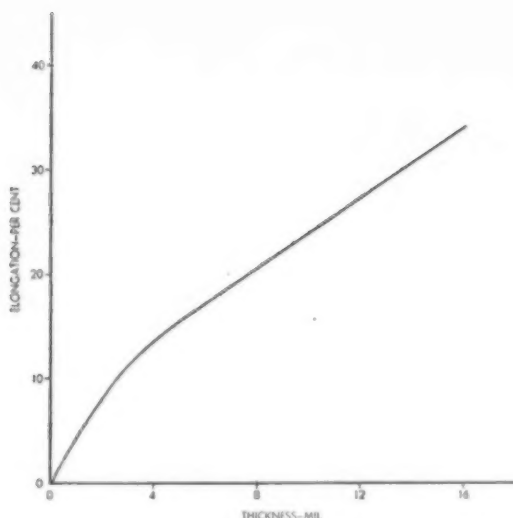


Fig. 6.—Variation of ductility with thickness of nickel coatings deposited from a Watts dull nickel solution (Brenner, Zentner and Jennings).

is not difficult, as the disc need not be accurate, either in circularity or diameter.

Ductility

The ductility of massive metals is normally expressed as percentage elongation. This elongation is the increase in length of a certain length (usually 2 in.) of a tensile test-piece after the test-piece has been fractured while its tensile strength is being determined. It is measured by fitting together the broken pieces of the tensile test-piece and measuring the increased distance between two gauge marks scribed before pulling. To do this on material which is about 0.001 in. in thickness is not easy, and accurate results are impossible to obtain. To overcome this problem, tensile test-pieces of about 0.005–0.010 in. thickness are normally obtained. Again the ductility changes with thickness, as shown in Fig. 6, taken from Brenner.

To obtain results applicable to the thicknesses normally encountered in commercial plating, one can again resort to the hydraulic bulge test previously described. The ductilities are then expressed as "significant strains" which, although not being the same as elongations from the simple tensile test, are of course relative. Using this relationship between "significant strain" and percentage elongation, the results can be converted by a formula to enable comparisons to be made with data obtained by other methods.

Although absolute values for ductility can only be obtained on electrolytic foils themselves, the plating industry is normally more interested in the behaviour of the coating on the article on to which it has been plated. Also, the obtaining of such foils in the correct shape and state for pulling is a tedious skilled technique, which cannot be easily adapted for production control work. Various attempts have therefore been made to develop methods for testing the ductility of the plated metal when it has been deposited to the usual plating thickness on some suitable basis metal. Fischer and

Barmann²⁶ and then Phillips and Clifton²⁷ suggested the use of the Erichsen cupping test, in which a hemispherical steel plunger is pushed into sheet metal. The test is normally carried on until the metal fractures, so as to obtain an indication of the ductility or formability of this metal. In the modified test the plated metal was bulged until the deposit cracked. The height of the dome produced was taken as a measure of the ductility of the deposit. This technique was tried by the author, but did not appear sensitive enough for nickel deposits. Brittle bright nickel deposits would crack when the dome was 2 to 3 mm. high, but ductile dull nickel would only stand bulging to 4–6 mm. before cracking took place. Furthermore, the results were not reproducible. The test should therefore be regarded as qualitative only.

In an attempt to obtain quantitative results, nickel-plated tensile test-pieces were then considered.⁹ These test-pieces are standard steel specimens, except that they are modified to have a reduced neck in the centre as shown in Fig. 7 (test-piece A). The tensile test-piece is plated with an average of 0.001 in. of nickel and then placed on a Hounsfield Tensometer and pulled. This extension is continued until the observer sees cracks appear in the deposit. If an automatic recorder is not available, another operator has to plot the extension occurring in the specimen against load applied. The load is then slowly released to remove the elastic deformation from the steel, leaving only the permanent elongation (see Fig. 8): this permanent elongation is taken as a measure of the ductility of the nickel. The ductility values are calculated from the number of squares on the plotting paper between the points where the load/extension and load/contraction curves cut the base line on the graph. If the gear ratio has been such as to give a magnification of 16/1, then this number of squares multiplied by 1.25 gives the ductility value of the deposits. The ductility values obtained are reproducible and comparative; duplicates should not differ by more than 10% or 1 unit, whichever is the greatest. By taking the hardness of deposits for which the ductility values were known, it has been calculated that these values are approximately three times the percentage elongation found with nickel foils. Incidentally, the use of brass instead of steel for the test-pieces has not so far been found to affect the results obtained, although only preliminary comparative tests have been made.

A refinement of the process has been introduced by Newman, who used a test-piece shaped as shown in Fig. 7 (Test-piece B). When pulling this test-piece, an

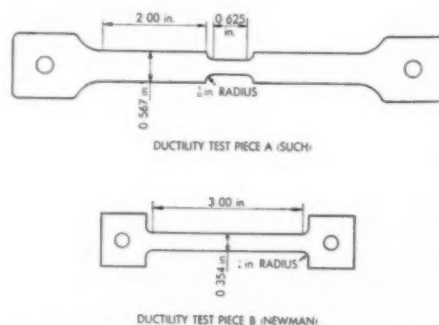


Fig. 7.—Two types of test piece suitable for determining the ductility of electrodeposited metals.

extensometer enables small elongations to be measured much more accurately and to be expressed directly as percentage elongation. However, the method is only applicable to brittle deposits; more ductile deposits do not crack by the time the limit of the extensometer range has been reached. As a 2 in. length of surface has to be watched, there is always a possibility that cracks may occur in the part not currently under observation. However, there is no doubt that the shorter test-piece is more convenient for beaker work.

Edwards, of the British Non-Ferrous Metals Research Association, has also developed a process for testing electrodeposited coatings in which the plate is left attached to the basis metal: this is the spiral bending test. This test involves bending a plated strip round a spiral-shaped former, whose radius of curvature is changing continuously. The point on the strip at which the first crack occurs is noted, and the percentage elongation is calculated from the radius of curvature of the former at this point. To ensure a uniform plate thickness of 0.001 in. on the test strips, they are cut from a large panel plated on one side only.

Unfortunately, this spiral bending test is only applicable to deposits of fairly low ductility—below 10%. There is no doubt that the chief use of the method, unless its range can be increased, will be for brittle deposits, where it is more sensitive than the tensile test. In the case of ductile deposits, no cracking at all, and therefore no quantitative results, can be obtained with the bending test as used at the moment.

Hardness

Most hardness determinations on electrodeposited metals have been made with either the Brinell or Vickers tester. The latter type of tester is more useful for electrodeposits, as it can be used for much harder surfaces than the Brinell, which is not accurate above 600 Brinell hardness. Unfortunately, the usual electrodeposit is so thin that the Vickers diamond either penetrates right through to the basis metal or the basis metal affects the hardness value obtained by its "anvil" effect, even if very light loads of 1 kg. are used. These light loads also give only a very small impression, particularly on hard surfaces, which is difficult to measure accurately. In order to avoid the interference of the basis metal and obtain valid hardness numbers, a much thicker coat must be used. The author has found that 0.014 in. of plate is sufficient for all but the very

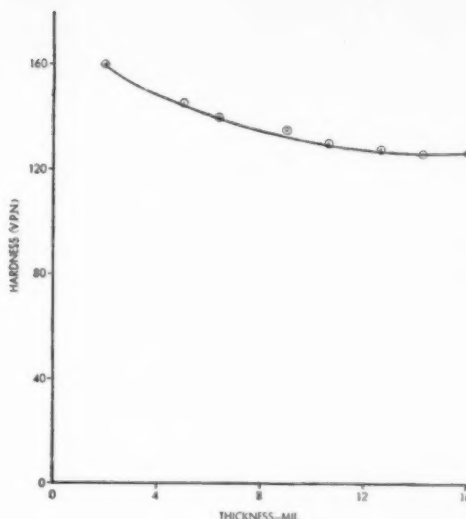


Fig. 9.—Variation of hardness with thickness of nickel coatings deposited from a Watts dull nickel solution (Brenner, Zentner and Jennings).

softest metals, provided that not more than a 2½ kg. load is used. This 2½ kg. load gives a fair sized impression, although still not as large as normally considered desirable. For deposits softer than 120 V.P.N. a 1 kg. load should be used. The plated article can be sectioned and hardness tests performed on the cross-section of the plate but, as the impression must not be too near the edge of the deposit, thicknesses of the order of 0.010 in. are still needed. Unfortunately the hardness values of these thick deposits are not necessarily the same as those of thinner layers, as has again been shown by Brenner (Fig. 9).

To obtain hardness values on plate thicknesses normally encountered means employing a micro-hardness tester. Very light loads down to 25 g. are available on these micro-hardness testers, of which there are several types. The depths of the impressions produced are very small and so they can be used perpendicularly on soft deposits as thin as 0.001 in. and on harder deposits even down to 0.0005 in. As the shape of the impression is easily modified by the surface contours of the plated surface, it is necessary to have a very highly polished surface to give the best results. If the surface is not extremely smooth, it is best to obtain a section of the cathode and after polishing this by the usual metallographic techniques, to do the hardness determination on the cross-section. As the hardness number obtained varies with the load employed, this should always be quoted when giving results. Comparison of these micro-hardness numbers with values obtained from macro-tests should only be regarded as approximate. A number of micro-hardness testing machines are available, some with standard pyramid indenters, and others with special indenters, such as the Knoop elongated pyramid and the double-cone type, which are claimed to facilitate more accurate determination of the size of the impression, particularly with light loads on hard surfaces.

Scratch tests have been used on electroplated surfaces, but are stated to be only suitable for soft and smooth deposits.

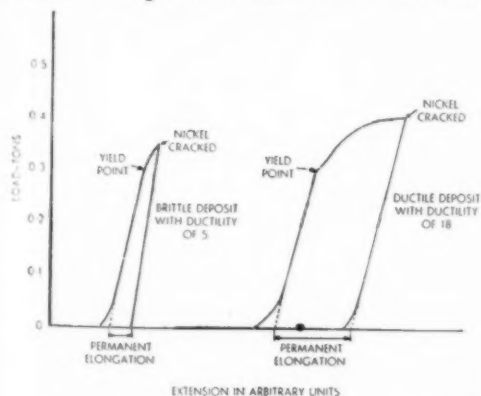


Fig. 8.—Graphs obtained when nickel plated steel test-pieces are pulled on the Tensometer.

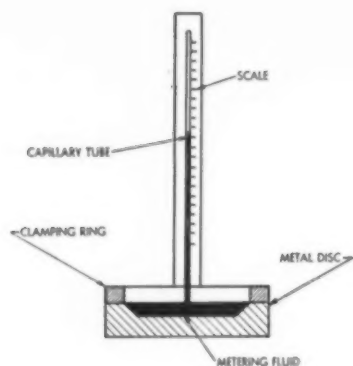


Fig. 10.—The Stresometer (Kushner).

Internal Stress

Ever since Stoney first measured the bending induced in a steel rule when it was plated on one side only, all methods of stress determination have been based on the change of shape found in a thin strip when so plated. The methods used by Brenner, Hammond and other workers are all basically the same, depending on determining the deflection produced by a known thickness of deposit. Some techniques, such as Hothersall's, have the advantage that the stress can be continually recorded as the metal is deposited, whereas only static measurements at one thickness can be made when the strip is clamped during plating. However, if the strip is clamped, suitable jigs can be used which enable a uniform deposit to be formed, avoiding the usual build-up at the edges. Various methods have been used to measure the small deflections produced either during the plating process or after removal of the coated strip from the bath, and Hammond has already summarised these methods.²⁸

Brenner, with his Spiral Contractometer,²⁹ has solved the problem of producing an even deposit on an instrument which also continuously records the change of curvature of strip as the plating thickness increases. The strip is coiled into the form of a helix, the upper end of which is fixed in relationship to an engraved dial. As the lower end of the helix is attached to a torque rod which in turn moves a pointer over the dial; any twist in the helix, as would be produced by plating it with a stressed deposit, is indicated by the movement of this pointer and can be measured in degrees. When the instrument has been calibrated, the movement in degrees can be expressed as stress. For further information on the use of the Spiral Contractometer the reader is referred to the original paper. There are claimed to be five main advantages of this instrument:—

- (1) As the helix is much longer than most straight strip cathodes its sensitivity is correspondingly greater.
- (2) All measurements are made in the plating bath and differences in temperature between that of the solution and the room do not therefore interfere.
- (3) No auxiliary optical apparatus or other measuring equipment is needed. Measurement can be made and results calculated in the plating shop.
- (4) The use of a coiled strip greatly reduces errors caused by transverse bending, for stress does not act

in one dimension only, it causes the strip to curl as well as bend.

(5) The instrument can be simply calibrated. This avoids laborious calculations and eliminates errors due to variations in the physical properties of the helix.

The main disadvantages of the Contractometer appear to be:—

- (1) As there is some effort involved in measuring and calibrating a helix, it must be used for a number of determinations. It must be unattached by the solution used for stripping off the plated coatings, and is therefore often made of stainless steel. However, a nickel strike solution must then be used, if good adherence of the deposit under test is to be ensured, and a special plating solution kept for this purpose.
- (2) The inside of the helix must be stopped off before every test, and the lacquer dissolved off before the helix is weighed again after plating, two more time consuming operations.
- (3) The instrument is not so robust as a strong metal jig in which a bent strip can be clamped, and it is more easily damaged in the conditions of a production plating shop.

A new instrument called the Stresometer has recently been announced. This was developed by Kushner in the U.S.A. and, although it again depends on plating on one side of a thin strip, the instrument is calibrated by hydrostatic pressure. In that respect it resembles the apparatus of Mills who was the first to measure stress in 1877. Mills silvered the bulb of a thermometer and noted how far the mercury column rose in the stem above the point equivalent to the temperature of the plating solution.

Kushner's Stresometer makes use of a thin metal disc clamped down to form the cover of a shallow chamber filled with some fluid (Fig. 10). As this chamber connects with a vertical capillary tube, any flexing of the disc produces a movement of the liquid in the tube. As the hydraulic magnification is high, the instrument is very sensitive and any slight movement of the disc due to stresses in the plate deposited on it will give a large easily readable movement of the fluid in the tube.

The main advantages of the instrument are its high sensitivity, ease of calibration, and the fact that continuous readings of stress can be made during the plating operation. The chief disadvantages are that if the disc is to be repeatedly used, stainless steel may have to be used, necessitating striking, and the alteration in volume of the metering fluid due to changes in temperature of the plating solution, for the instrument which is designed like a thermometer also acts as one. However, the movement of the liquid in the capillary due to temperature can be calculated and allowed for.

Acknowledgment

Grateful acknowledgment is made to the Directors of Wilmot Breeden, Ltd., for permission to publish this paper.

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High Pressure Jet Burners

New Technique Aids Localised Heating

A NEW type of high pressure gas burner promises to revolutionise many processes where high intensity heating is demanded, such as in the localised heating of metal parts. In this type of burner, combustion is completed very rapidly in a refractory chamber or tunnel and the resultant gases, at a temperature of 1,750–1,850° C. are discharged from a narrow opening at the tunnel mouth at supersonic velocities. The combination of high temperature and high velocity gives these burners their phenomenal heating potentials. Some indication of the latter is given by the fact that in pre-heating prior to metal deposition, the required portion of a 2-ton valve body was heated to 750° C. in 12 minutes, a process which previously took 6 hours.

The science of burner design has, up to recent years, concentrated upon improvements in the entrainment and mixing of air and gas and the attainment of the maximum rate of flame propagation throughout this mixture with minimum absorption of the pressure energies available in the gas, or gas and air streams. The rate at which combustion occurs is limited, and if the mixture volume issuing from the nozzle is too great, the flames will leave the burner and become extinguished. It will be appreciated, therefore, that the rate of combustion of a theoretical mixture is controlled by three major factors:—

- (1) The degree of admixture of any primary air supply with the gas.
- (2) The rate at which air can diffuse into the gas from the atmosphere.
- (3) The rate at which, in this mixture, centres of combustion can become sufficiently close to unburnt mixtures to promote their ignition.

The third factor is, itself, dependent on such factors as area of flame envelope; temperature of combustible mixture; the initiation, breaking and branching of chain reactions which take place prior to actual visible ignition; and other complex factors, all of which can be said to be physical constants of the mixture and burner type.

From this it would appear that the fastest possible rate of combustion has been reached where air and gas are premixed in theoretical proportions prior to the burner. If, however, the flames produced by such systems are surrounded with a refractory tunnel, a rapid increase in combustion rates occurs, as can be seen from Table I.

Combustion Mechanism of Jet Burner

Early workers¹ on this type of combustion came to the conclusion that the increase in combustion rate was primarily influenced by a catalytic reaction taking place along the refractory wall, exciting increased centres of combustion which would naturally lead to the more intense combustion, as illustrated in the "porous bed" type of mechanism. More recently, Leason,² working at Leeds University, showed that even at these high velocities, the tunnel walls held round them a cool zone or "dead space," and from temperature measurement and velocity distributions, he concluded that the mechanism differed little from that of more conventional systems, and that

TABLE I.

Burner Type	Volume of Gas Burned (cu. ft./hr.)	Volume of Flame (cu. ft.)	Combustion Rate (B.Th.U./cu. ft. of flame)	Flame Temperature (° C.)
Non-aerated ..	600	0.45	0.67×10^4	1,750 to 1,850
Aerated ..	600	0.65	0.45×10^4	
Air blast ..	600	0.145	2.07×10^4	
Tunnel burners .	600	0.00345	115×10^4	
Lucas combustor used in aircraft jet engines .	10,000		10×10^4	

the turbulent conditions present within the tunnel gave rise to an increased flame area, accelerating the progress of the flame front. Howland and Thomas,³ however, working for the Gas Research Board, found that, in other types of burner system, turbulence equal in intensity to that found in tunnel burners did not produce the high rate of combustion per unit flame volume. Norrish and Patnaik,⁴ found from stroboscopic examination of the flame that combustion took place as a series of explosions at high velocity, and proved by spectrograph that the emission from the flame front is not typical of normal turbulent combustion, thus showing the combustion to be of a special nature.

Why the explosive combustion should take place is not altogether clear, and a short account of the combustion of static air gas mixtures would possibly throw some light on the problem. If a mixture of air and gas is exploded by means of a spark in a tube open at one end, the resultant flame travels from the closed end of the tube at a uniform velocity. Under suitable conditions, it would then pass through a transition period of vibrational movement which accelerates to detonation where sonic velocities are attained. In the second stage of explosion, acceleration of the flame front takes place and a high concentration of shock waves, which have long been associated with ignition phenomena, is found to be present in the tube. It is possible that, under the influence of shock waves, the flame front is accelerated, retarded or even extinguished. These shock waves are produced by external means, such as a spark ignition, or can be produced spontaneously in, or just behind, the flame front. Under favourable conditions, the flame front can attain sufficient velocity to produce a highly luminous wave with the accompanying sound characteristic of detonation.

From a conception of this type, the rapid increase in combustion rate occurring by surrounding a flame with a refractory tunnel can be explained, namely, when combustion takes place, compression waves are radiated from a point at the base of the tunnel and are reflected by its walls and, upon striking the flame front, they cause an increase in flame speed.

The presence of shock waves is abundantly clear from the high noise level produced by a tunnel burner. These sound waves are sufficient in magnitude to produce a deafening resonance of the whole gas stream within the tunnel. Research into sound production is now in progress at Leeds University which, when completed will, it is hoped, throw further light on this problem, and

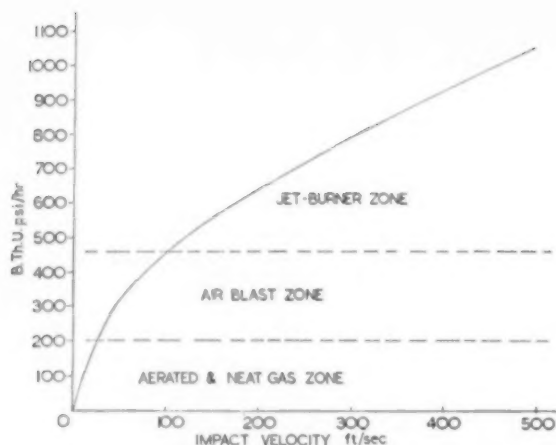


Fig. 1.—Effect of velocity of combustion products on the heat potential of burners.

possibly establish a definite theory of the mechanism of jet burner combustion.

Heat Potential of Burner

Although some heat processes at present use flame radiation as the primary source of heat transfer, convection is the major heat mechanism employed in the bulk of cases. Combustion products at around 1,850° C. impinge on the surface of the material to be heated, but there is no actual contact, as heat is transferred through a layer of stagnant gas on the surface. The rate of heat transfer depends, therefore, on:—

- (1) The heat transfer coefficient of the boundary layer.
- (2) The temperature gradient across the layer.
- (3) The thickness of the layer.

It will be appreciated that the thickness of the boundary layer is decreased by increasing the velocity of impact of the gases issuing from the burner.

From Fig. 1, it will be seen that the heat potential of a burner is not merely dependent on the temperature of the stream of products issuing from it, but also on the velocity or kinetic energy of this stream. In normal systems, thermal expansion due to combustion of the mixture takes place in three dimensions, and the resultant hot stream of products is increased little in velocity by this expansion. If the flame is then surrounded by a refractory tunnel of divergent or parallel type, as in the normal tunnel burner, much greater discharge velocities are achieved, with accompanying increases in the heating potentialities of the burner. On completing combustion in the jet burner, the flow rate of the products up the tunnel to the point at which they are discharged to atmosphere is accelerated. This is accomplished by using a convergent tunnel, with which velocities as high as 1,000 m.p.h. have been achieved.

Whilst heat input is vastly greater with jet type burners, the heat losses from the body being heated are the same regardless of the rate of heating, and are the sum of conduction losses from the area being heated, through the material itself, and radiation losses. The temperature at which heat input is equal to heat losses is shown in Table II for various types of burner, with the flame impinging on one face of a 1 in. cube of steel,

TABLE II.

Burner Type	Temperature Attained at Equilibrium (° F.)	Heat Required to Raise Steel Cube to Equilibrium (B.Th.U.)	Velocity of Products onto One Face of Cube (ft./sec.)	Time Required to Reach Equilibrium (min.)
Jet	1,520	46.0	754.0	2.1
Air blast	1,100	33.3	56.8	7.2
Aerated	810	24.6	24.7	12.3
Neat Gas	690	20.9	18.7	17.5

together with the time to attain equilibrium. The shorter heating times and higher temperatures attainable with jet burners, have greatly reduced the necessity for surrounding the work to be heated with an insulating refractory chamber to prevent heat losses. Thus the development of furnaceless heating has emerged, with the possibility of its extensive use.

Jet Burner Construction

In the past, efforts have been made to standardise burners, but jet burners, where the maximum point of heat release is only some 1 in. from the burner mouth, must be "tailor-made" to the job in hand. If this is to be done, then the use of pre-fired blocks with the accompanying high pattern costs involved must be dispensed with, and materials suitable for ramming or casting used instead. As many of the latter brands are available, it would appear that a very wide choice exists but, whilst these are very excellent for smaller parallel sided or divergent tunnels, all are not suitable for jet burners with convergent tunnels. A short list of the arduous duties and required properties may help to illustrate this point:—

- (1) The material must not subside or lose strength at temperatures as high as 1,750° C.
- (2) The material should resist thermal shock, since tunnel working temperature is attained in some 30 seconds.
- (3) The fired and unfired mechanical strength of the material should be as high as possible, as curing of the refractory is never completed in a tunnel, and in the outer layers the material may rely upon unfired strength.
- (4) Volume stability is also of great importance, as will be realised from the previous requirement. If curing is incomplete, any shrinkage or growth on firing will result in distortion with its resultant cracking.
- (5) Thermal conductivity should be low to reduce the inevitable burner losses to a minimum, and also because materials of high thermal conductivity will cause overheating of the perforated back plate which may, in turn, promote ignition of the mixture behind this plate, should the mixture velocity fall.

In view of the foregoing, the choice appears to be limited to those having the following constitution:—

Alumina	60% min.
Silica	36% max.
Impurities and alkali	3% max.

The grog size should be large and widely graded to give low shrinkage and high density.

The second and most serious problem with very large burners is the terrific noise produced. The tunnel length is of prime importance in prevention of noise, although many other factors are found to influence noise produc-

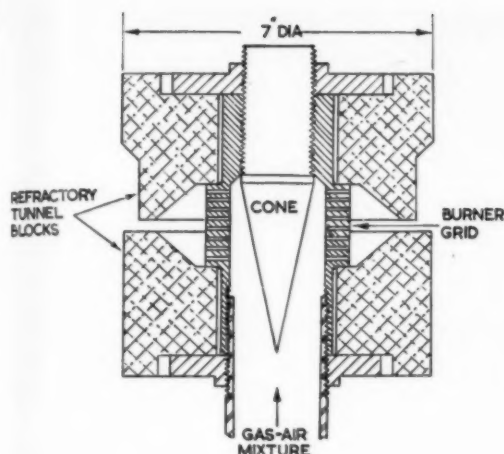
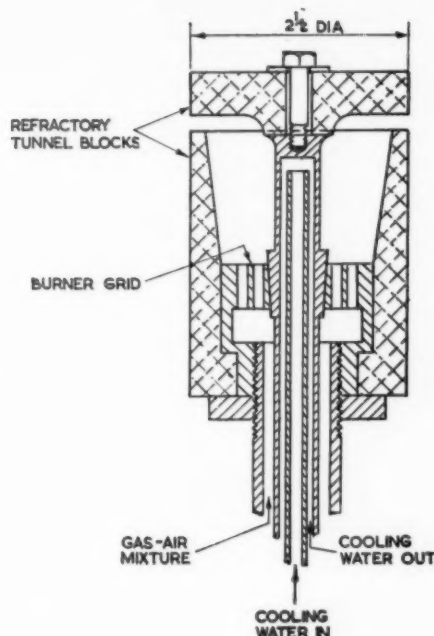


Fig. 2.—Jet burners for heating valve seats.



tion. The major components of the burner concerned are :—

- (a) Metal or ceramic back plate.
- (b) Tunnel form.
- (c) Tunnel material.
- (d) Tunnel exit.

and a study of these factors has led to the following rather empirical conclusions :—

- (a) The susceptibility of a tunnel to resonance has been found to depend upon the size of the perforations through which the gas and air mixture passes. The larger these perforations, the less likely is the tunnel to resonate, as the flame front is reduced in area and is consequently positioned nearer the tunnel mouth. The size to which perforations can be increased depend upon the degree of turn down required, as a danger of burner light back is increased.

- (b) The basic tunnel form or section is of great importance if resonance is to be avoided, and the following general principles have been used as a guide :—

- (i) The parallel sided tunnel form should, whenever possible, be avoided, as stabilisation of the combustion is difficult within these parallel sections.
- (ii) The tunnel with a convergent section, having equal taper to reduce reflection of sound shock waves within the tunnel, provides the greatest stability.
- (iii) 10°–20° convergent taper is found most satisfactory, but this is rather dependent upon the exit velocity required.
- (iv) Stagnant pockets of gas or areas of low velocity should be reduced to a minimum, as turbulence created by these pockets may again cause instability.
- (v) It is important that burners be designed for the particular purpose for which they are required, as is the general rule in all furnace work.
- (vi) Excess tunnel volume should never be permitted, because resonance is favoured by such conditions. The burner efficiency, that is heat

to work, suffers seriously in a turned down or an over tunnelled condition.

- (c) In addition to the refractory properties previously mentioned, the nature of the tunnel surface produced by a material is of importance in the prevention of resonance. It has been found that the smoother the material, the more likely it is to resonate due, most probably, to the absorption of shock waves by a rougher material.

Typical Applications

Reference has already been made to the use of jet burners for pre-heating valve seats prior to metal deposition. By the use of correctly positioned jet burners of the types shown in Fig. 2, the internal seats of valves weighing up to 2½ tons can be raised to a temperature of 750° C. in some 12 minutes, although the seats are located in highly conductive structures.

A further illustration of the remarkable achievements of jet burner heating was demonstrated at the Leeds works of Clayton, Son & Co., Ltd., on the occasion of a press visit organised by the Gas Council in conjunction with the North Eastern Gas Board. For over fifty years, Clayton's have been making large diameter steel pipes to meet the requirements of the water, gas, oil and sewage engineering industries, by what is now known in the trade as the "water gas roller welding process." This technique has continued in use despite the development of automatic arc welding, a process which is not considered suitable for universal application.

The machine used is substantially the same as that devised by the founder of the firm, Mr. Lawrence Clayton in 1906. Plate is rolled to form a ½-in. lap joint, which is then heated to some 1,500° C. prior to rolling under a pressure of 12½ tons. Each section of tube, just over 2 ft. long, is heated and rolled three times before passing on to the next one, allowing a 3 in. overlap. The tube is moved

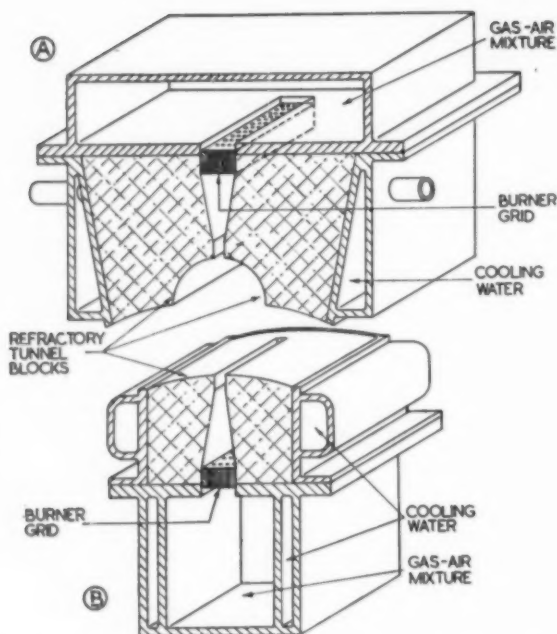


Fig. 3.—Jet burners for heating tube prior to roller welding operation: A—external burner; B—Internal burner.

along by a hydraulically operated carriage. The capacity of the machine ranges from 14 in. to 72 in. in diameter, and up to 26 ft. in length.

Since the attainment of a temperature of $1,500^{\circ}\text{C}$. in open atmosphere is impossible with coal gas/air mixture in conventional burners, very large jet burners had to be designed. They are slightly different for use inside and outside the tube and the two versions are shown in Fig. 3, whilst the actual set-up is shown in Fig. 4, before heating commences. The new burner consists essentially of a rectangular metal case surrounding a tapered refractory tunnel. The gas/air mixture is fed in through a series of holes opposite the outlet, through which, after combustion, the hot gases are expelled at high speed onto the surface of the tube. Gas at 2 lb./sq. in. and air at $2\frac{1}{2}$ lb./sq. in. are provided by a compressing plant.

As the name of the process suggests, the attainment of the working temperature of $1,500^{\circ}\text{C}$. was originally achieved with water gas as fuel, but the advent of the jet burners made possible the use of coal gas. Comparative figures show that there has been effected a reduction of fuel costs amounting to 50%. Of equal importance is the fact that a $44\frac{1}{2}$ minute saving in a total welding time of 119 minutes represents a $26\frac{1}{2}\%$ increase in production rate.

There appears to be no reason why similar results should not be obtained in many applications of these burners where they are designed to replace the more traditional systems, and also why their use should not be extended to other process jobs where fuels other than coal gas are used at present. The examples quoted, although rather specialised, show that in this type of burner, where heating potentials are a product of temperature and high velocity, coal gas can be used to provide a heating service at a lower all-in cost than has hitherto been possible.

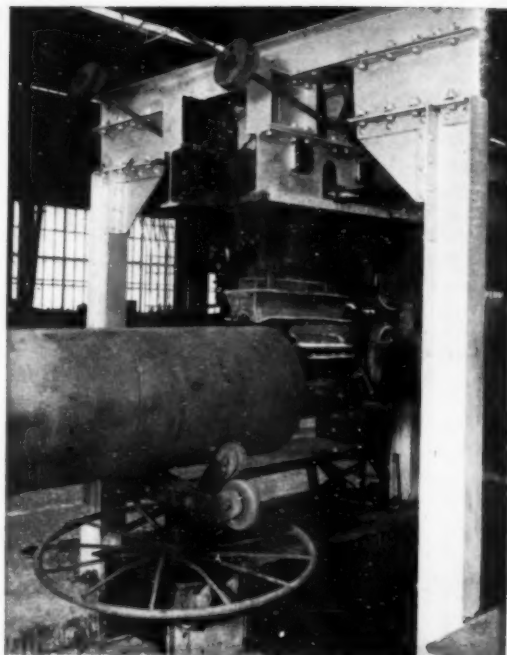


Fig. 4.—Set up for welding large diameter steel tubes at the works of Clayton, Son & Co., Ltd.

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Welding Safety Information Sheets

THE Health and Safety Sub-Committee of the Institute of Welding is preparing a series of information sheets under the general title of "Accidents and their Prevention," and the first of these has now been published. It deals with the dangers of carelessly releasing free oxygen gas into confined spaces. It is hoped that these information sheets will encourage workpeople to be more conscious of the common causes of accidents in the use of welding and cutting equipment, and that they will help to reduce the number of accidents still further. In the preparation of these sheets the Sub-Committee is taking particular care to avoid any impression that welding is a hazardous job.

Metallurgical Library Meeting

THE Metals Division of the Special Libraries Association will be in session during the Second World Metallurgical Congress to be held in Chicago from November 6th to 8th, 1957. Speakers from France, Germany and the United Kingdom will take part in addition to those from Canada and the United States. A library display booth and information centre will be available at the International Amphitheatre. Overseas metallurgists, attending the Congress are recommended to take the opportunity of visiting the John Crerar Library, the largest technical library in the world.

A Metallurgist's View of Metallurgy*

By Earle E. Schumacher†

A modern metallurgy department serving a communications organisation must keep pace with advances in both metals science and communications technology. From the precise measurement of elusive physical and electrical properties to the formulation of specific alloys tailored to meet rigid design specifications, the metallurgist's skills must embrace a variety of techniques and fundamental processes. At the Bell Telephone Laboratories, the Metallurgy Department is directly concerned with all phases of metallurgical research and development from materials testing to fundamental studies of the solid state.

THE Bell System is built on metal—in the vast conductor systems spanning the country, in the switching apparatus in central offices, in the telephone in the customer's home and in thousands of miles of submarine cable. Last year, over half a billion pounds of metal were added to the Bell System plant.

The required quantities of some metals are enormous: in 1956 the Bell System used over 200,000,000 lb. each of copper and steel, around 100,000,000 lb. of lead, and masses of zinc, aluminium, nickel and tin. These and other metals, from the less common to the truly rare, provide the conductors, magnets, resistors, capacitors, springs, frames, even the just plain hardware of the telephone plant. For each application a metal must be selected, and this is the responsibility of the Laboratories Metallurgical Research Department.

The metallurgist in this view is primarily an engineer; that is, he is both technologist and economist. He is well grounded not only in the physical and mechanical properties of materials possible for an application, but intimate as well with quantity required, availability, fabrication methods, market conditions and cost, government regulations, and with use of the device itself, its life expectancy, and its service environment. To hold to this view of the metallurgist's function, however, is to over-simplify his role in the face of the advancement of communications technology.

The metallurgist has long been a scientist—part physicist, part chemist, part crystallographer. Nevertheless, until recently much of the basic science of metals has been purely descriptive; the knowledge of relations between processing and properties has been empirical. Now, modern physics has advanced understanding of the solid state to the point where the metallurgist will relate properties of the processed material to its atomic and micro-structural state. It becomes possible to predict and control properties by manipulating composition and treatment. The same advances in physics have rendered communications technology more complex, particularly with the introduction of solid-state devices such as the transistor. The Metallurgical Research Department must develop, control and recommend the material not only for such items as capacitor mounting brackets but also for transistors, computer memory devices and solid-state microwave devices.

About half of the programme for the Laboratories Metallurgical Research Department originates from the

intensely specialised nature of Bell System requirements. The commercial metal producer quite simply cannot afford to undertake the research and development necessary to such specialised application. Nor can we, the System, in general afford to undertake the necessary education of producers in our metals needs. Moreover, it is essential that metals research and device research proceed intimately integrated—indeed, to the point of indistinction between whether a new material creates a device, or a new device gives conception to the required material. Herein lies the origin of the remaining half of the Metallurgical Research Department programme, and the origin of its activities at the fundamental research level.

The interplay between technology and basic research is illustrated by our use of nickel—a metal in critically short supply. Through a team approach to alloy development, which typically has included the active participation and strenuous efforts of the Western Electric Co., we have been able to reduce our demand for nickel substantially. It is estimated that our consumption would be more than twice the present rate if it were not for the technological advances and substitutions which have been made. Furthermore, this reduction has been effected not only without jeopardising the quality of communication but while steadily improving it.

Importance of Fundamental Knowledge

Behind the reduction in requirements for critical nickel through substitutions is a vast accumulation of fundamental knowledge about the properties of materials and their processing—much of it acquired by the Laboratories research teams. The origin and control of fundamental properties such as electrical and thermal conductivity, magnetism, fatigue, yield strength, creep strength and hardness are continuing research efforts. These properties are the consequence of the metal structure and composition. The metallurgist therefore carries out fundamental studies to discover how, by properly combining atoms, the desired properties can be obtained or modified. Some examples taken from current metallurgical research projects may help to show the diversity of our studies, from "practical" to fundamental, as well as their common response to the challenge to increase our control of the properties of metals and alloys.

The mechanical properties of a metal are simply the strength properties significant to mechanical service—tensile, yield and creep strengths and endurance to fatigue. New apparatus designs and life requirement increases have necessitated re-examination of these

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Removing the mould from the high vacuum furnace.

mechanical properties. The change from manual to machine switching, for example, required the use of spring material with better fatigue life than brass. The fatigue properties of phosphor bronze or nickel silver would meet these life requirements. However, the restrictions on the use of tin and nickel imposed during and since the war dictated the use of material which contain less nickel or tin. Metallurgical studies showed that by better control over composition limits, fabrication to obtain fine grain size, and control of residual stresses, improved fatigue strengths could be obtained with alloys of lower tin or nickel content.

Problems come with progress. Flat springs used in the older types of telephone relay gave service performances which could be predicted accurately on the basis of fatigue tests carried through on hundred million stress cycles; a proposed material could be fully evaluated in about six weeks. The relays employed in automatic message accounting equipment (AMA), on the other hand, must operate into the billions of cycles without failure. To evaluate a material properly on the basis of a billion test cycles would require about 15 months; on the basis of ten billion test cycles, 11 to 12 years. By invoking the aid of the powerful statistical methods developed for quality control, however, it is now possible by extrapolation to obtain the required accuracy of prediction from feasible tests on a more limited basis—the effects of all variables of material and test machine being under statistical control. The metallurgy group is thus implemented by the resources of modern mathematics, and rather abstract mathematical research is applied to a very practical engineering problem.

Another practical area of metallurgical study concerns the investigation of the properties and applications of solders. Literally billions of soldered connections are made each year, and thousands of tons of solder are

consumed in the Bell System. No more than one faulty joint in 50,000 is the desired quality goal; even one such bad joint could cause a serious circuit failure.

The development of solder alloys and improved soldering methods is a major activity. Solders containing much less tin than the alloys presently used may be required in any future period of tin scarcity, and hence the effects of other elements and new compositions are constantly being evaluated. The solderability of metallic parts is an elusive property that is difficult to define. But it is of vital importance in mass soldering methods and it can now be determined readily. A test in which the samples are dipped in molten solder will establish the relative ease with which the metal surfaces will be wet by the solder. A spread test or a capillary rise test can also be used to evaluate numerically the effects of solders, fluxes and metal surfaces. This ability to assign a parameter that weighs so many variables has provided invaluable insurance against the expensive hazard of unreliable joints.

Plastic Flow

Creep strength is another property of metals that is affected by so many variables that its evaluation is essentially statistical. Creep is the slow deformation of a material under a stress far less than that needed to produce immediate plastic flow; it is the bane of the cable engineer. Creep studies necessitated by the pressurising of paper insulated cables, to preserve the dielectric properties of the insulator, have led to the development of lead alloys having improved creep characteristics for use in the sleeves which cover cable splices. The introduction of composite cable designs and aluminium cable sheath has required the development of new testing techniques to evaluate the probable service life of the new designs.

In the evolution of aluminium cable sheath we perceive the links among technology, development and research. It has been known for many years that aluminium would offer advantages in strength, weight and cost over lead alloys as a cable sheathing material. In Germany before the war, short lengths of aluminium sheath had been extruded over paper insulated cores. The temperatures required, however, were such that the paper was badly scorched when the presses were stopped for recharging. This made the extrusion of continuous lengths uncommercial.

Yet, because of the undoubted attractiveness of aluminium sheath for telephone cables, the subject was explored at the Laboratories. Instead of attempting to modify existing extrusion devices, basic studies were carried out on plasticity and the mechanics of the flow of materials under pressure through cavities and over surfaces. The information thus obtained has been applied to the design of extrusion equipment in which advantage is taken of preferred flow paths to keep pressures at a minimum. Extrusion experiments using this equipment show that die contours are of great importance in determining extrusion pressures and perfection of the sheath.

The plasticity measurements on lead and aluminium indicated that aluminium would require about ten times the pressure normally used for lead alloys in conventional extrusion equipment. However, the new laboratory equipment, based on the exploratory studies, permits the extrusion of aluminium at temperatures that do not scorch paper during recharging and at pressures only about 10% higher than those used for

lead in conventional equipment. Thus, the feasibility of extruding aluminium sheath commercially was established and the ground cleared for introducing aluminium sheath into the Bell System plant.

A piece of metal is rarely useful until it has undergone some plastic fabrication to alter its shape and properties. Our present basic plasticity studies include a programme on the effect of temperature and rate of straining on the flow of metals. Although it has long been known that, at a given state of strain, the yield stress of a metal depends on the temperature and on the rate at which the metal was previously deformed to the state of interest, only a few investigations had previously been conducted, in this field of activity.

Early experimental data from our fundamental programme now indicate that a unique relation exists between the plastic behaviour of metal and its yield stress. Two specimens of the same metal deformed in different ways to a state of the same yield stress appear to exhibit the same rate of work hardening. As temperatures change they should have the same increase or decrease of the yield stress. The establishment of this observation as a general relation will be of considerable importance to the formulation of the fundamental theory of plasticity. This is basic metallurgical research.

Atomic Scale Defects in Metals

It now appears that many properties, in particular mechanical properties, depend mostly upon the behaviour of atomic-scale defects that ordinarily occur in metal and alloy structures. These defects include dislocations, vacant atom sites, interstitial atoms and impurity atoms. An attack is being made on the dual problems of how these defects act and interact, and of finding means to control their behaviour. A new means to achieve such control and to conduct basic experiments on the properties of defects is now available in high intensity beta particle and neutron bombardment in modern accelerators and nuclear reactors.

In an important part of this programme on imperfections in metals, currently in progress, ultrasonic acoustic



Securing test leads for low temperature elasticity measurements.

waves are being used to detect and study the motion of dislocations. Clean, uncomplicated experiments are possible in which acoustic shear waves of appropriate frequency are sent into a relatively perfect metal crystal. Dislocations in the structure of the crystal may be set into vibration by these waves, thereby absorbing and dissipating some of the acoustic energy. The observed attenuation is thus related to the nature of the dislocations present and to the ease with which they can move about in the structure. This method serves to identify the structural perturbations which aid or oppose such motion.

Another aspect of the programme on plasticity makes use of the recent finding that germanium and silicon, usually thought of as brittle, can be plastically deformed. We have deformed these diamond-like semimetals in tension and compression by achieving the appropriate conditions, and we have discovered two unusual characteristics of these materials which make them particularly valuable in the study of defects. First, the position of dislocation in these crystals can be revealed in the form of etch pits on specially prepared surfaces. Second, the presence of both vacancies and interstitial atoms can be detected through their effects on electrical conductivity. Studies of these etch pits have given experimental confirmation to much of the dislocation theory of plasticity. Conductivity studies have also confirmed the predicted formation of vacancies and interstitial atoms during plastic deformation and therefore hold promise of spelling out on the atomic scale the closely related mechanism of how metals are hardened by deformation.

A fourth attack on plasticity problems is being made through studies of the metal whiskers found growing spontaneously on metal surfaces. These whiskers may often be so free from lattice defects that they do not show plastic behaviour of the ordinary kind. They therefore remain elastic at stresses which are orders of magnitude larger than the usual yield strength levels observed in ordinary specimens of the same metal. Metallurgists are learning the conditions under which



A tensile test in progress in the automatic Instron testing machine.

such defect-free structures can be grown, and are producing specimens of many materials with these unusual mechanical properties.

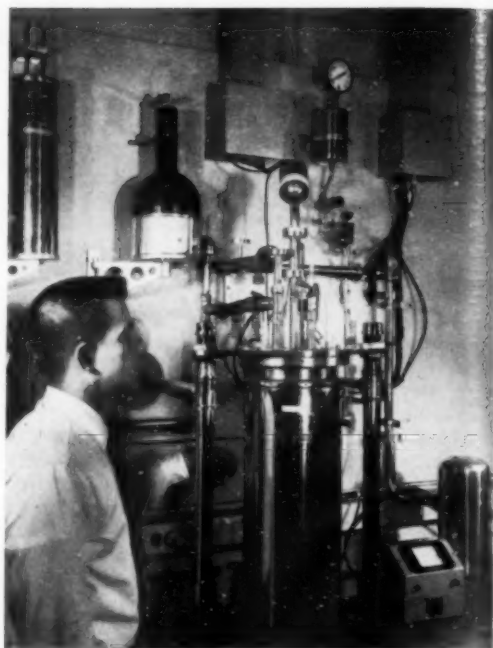
The role of defects in altering the electrical properties of semi-conductors is as important to the use of these materials in solid-state electronic devices as it is to research in plasticity. Bell Laboratories metallurgists have pioneered in the preparation of semiconductors such as silicon and germanium—first, for crystal detectors used in radar and microwave relay, and later, for research culminating in the transistor, the silicon solar battery and the solid-state diode. They have prepared the purest germanium and silicon known to man, containing less than one part of harmful impurity in ten-billion of the semi-conductor. The techniques of zone melting used to purify these materials have been widely adopted by the semiconductor industry and have been extended to other semiconductors, to metals and to chemicals.

The programme now in progress involves the preparation of extremely pure metals and a study of their physical properties. This includes a fundamental study of the preparation of pure and perfect single crystals of various metals, so that their properties can be investigated without the complicating effects of grain boundaries, impurities, dislocations, lattice vacancies and the like. In these respects the pure single crystals command the same interest as the apparently unrelated metal whiskers. It is expected that these studies will be extended to the rare metals, such as scandium, yttrium, and the rare earths only recently made available in elemental form. Properties here are almost completely unknown; there is opportunity for exploration in virgin territory.

Magnetic Properties

Metallurgical concern with magnetic properties antedates by many years any equal interest in semiconductors or rare metals. The Bell System needs superior magnetic materials to make possible the tenfold or more reduction in size required for miniaturised equipment, and to provide the more powerful permanent magnets essential to the development of more and more efficient devices. Perhaps we ought to consider the permanent magnet as the prototype solid-state electronic device. Theory has told us that magnets made of very fine particles, each consisting of a single magnetic domain, should have very good permanent magnet qualities. Ways to make better magnets of oriented assemblies of such particles are constantly under development. Among the materials being studied are iron, manganese bismuthide and barium-iron oxides (Ferroxdur). Effects of particle shape, size and internal structure are being revealed, and valuable fabrication experience is being acquired.

The development of the mineral-like magnetic materials known as *ferrites* is one of our chief concerns. These materials, made from compounds of iron oxide in combination with other oxides, have remarkable magnetic properties and are widely used throughout the Bell System. It is instructive to contemplate an historic paradox here. Man's acquaintance with magnets began with the ancient lodestone, a natural ferrite. After centuries of study, a revolution in physics, and millions of dollars invested in research, we are now looking with new perspectives at similar structures of which lodestone is a prototype.



Low temperature calorimeter being put into operation.

Metallurgists have now learned enough about ferrites to custom-design compositions and treatments that will meet many pre-set specifications. An example is the ferrite core material for inductors in modern communication equipment. The trend has been towards ever higher carrier frequencies so that more information can be transmitted in a given communication channel. A serious limitation on this development has long been losses, particularly eddy current losses in inductors, that increase rapidly with frequency and cause severe attenuation. The development of ferrite cores, designed to have good magnetic properties but with extremely low electrical conductivity, has significantly reduced these losses and made possible a large extension of operating frequencies.

Another quite important application of these materials is for the isolators needed in microwave transmission systems. Such devices may be used to act as a one-way valve which, by isolating oscillator from antenna, permit a signal to pass towards the antenna, but prevent reflected waves from perturbing the oscillator. Large gains in efficiency result. The frequency at which these devices operate is now controllable through small changes in composition of ferrites.

A promising application of ferrites is for "square-loop" materials, designed to have essentially square hysteresis loops. The magnetisation of these materials remains constant in direction and strength until a sufficient reverse field is applied. Then a sudden complete reversal of magnetisation occurs. These "yes" or "no" directions of magnetisation can be used much as relays are used to store information, but with the great advantage of requiring no moving parts. Devices based on this principle are potentially of great value for use in computers, magnetic storage and switching applications.

Low Temperature Research

The current trend in fundamental metallurgical research towards convergence with solid-state physics is exemplified by the types of physical measurement we are now obliged to make, and in the laboratory facilities required by an active group. Thus, the observation of physical and mechanical phenomena at low temperatures, approaching absolute zero, has been generally neglected by metallurgists until fairly recently. For a number of years, however, the Metallurgical Research Department has had in operation a liquid helium cryostat, which has been used for studying metals, ferrites, and semiconductors by acoustical methods at extremely low temperatures. Recently, a new laboratory has also been established for additional calorimetric and cryogenic measurements. These new facilities will permit us to make precise measurements of heat capacities and other thermodynamic quantities over temperatures ranging from near absolute zero to several hundred degrees above room temperature. The information obtained will add significantly to our knowledge of phase equilibria in solids, as well as to our understanding of interatomic forces and modes of thermal vibration in solids.

The new laboratory is also engaged in studies of transport phenomena at very low temperatures. The idea behind this work is that, at these temperatures, scattering of charge carriers by thermal vibration of the

atoms is insignificant compared to scatter by atomic defects of the type referred to previously. In this way, extremely small effects of impurity atoms, vacancies and interstitial atoms can be studied. The phenomena under investigation are electrical conductivity, the Hall effect in ultra-pure material, the Nernst effect and the thermoelectric effect. Measurements of electrical conductivity of metals are so precise that they reveal the presence of trace impurities in amounts less than can be detected by other sensitive means such as the spectroscope.

The Future of Metallurgy

Despite the compelling interest and deep significance of this work it does not mean that metallurgy will become a subdivision of solid state physics. It does mean, however, that fundamental research in metallurgy must proceed with the pace and intensity of that in sister sciences. This is essential if the metallurgical function of providing the metallic materials for the device-products of modern thought is to be fulfilled. However complex his laboratory tools and abstract his intellectual tools, the metallurgist will always be first and finally concerned with the product of furnace and rolling mill. The view of a Laboratories metallurgist must embrace all phases of metallurgy, fundamental as well as practical, to envisage the means of introducing new developments into practice so that the Bell System may have products essential to its continuing growth.

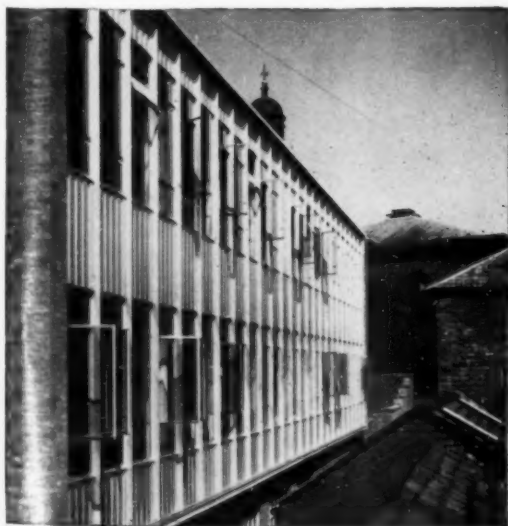
Aluminium Curtain Walling on New Telephone Exchange

ALTHOUGH it is not expected to come into operation until the middle of next year, the building in which Banbury's new telephone exchange is being installed is virtually complete. A fine modern three-storey building to the rear of the Head Post Office, of which it is an extension, it presents two handsome facades which, unfortunately, are not readily seen from the main thoroughfare. These two facades are for the most part in aluminium curtain walling, covering areas of 2,600 and 1,100 sq. ft., with aluminium windows and

aluminium infilling panels. The sheet and sections used, which were supplied by Northern Aluminium Co., Ltd., whose Banbury Works are little more than a mile from the installation, are in two different alloys, but to maintain uniform appearance all were caustic etched, then anodised. The result is completely successful and the metalwork is in pleasing harmony with its surroundings.

The curtain-walling system, which was installed under licence by George Wragge, Ltd., who also supplied the windows, comprises Williams and Williams standard Wallspan sections in Noral 50SWP alloy and also a channel section specially designed to drain off condensation in accordance with Ministry of Works requirements. Such a precaution was necessary in view of the sensitivity of the equipment used in the exchange. The infilling takes the form of Robertson Q-Panel, supplied by Robertson Thain, Ltd., which consists of an outer face of box-ribbed aluminium sheet in Noral 3S alloy and an inner flat tray of zinc-coated steel, with a filling of glass-fibre insulating material. The architect is T. F. Winterburn, A.R.I.B.A., of the Chief Architect's Division of the Ministry of Works, and the main contractors are Hinkins and Frewin, Ltd., Banbury.

The erection of the new building will enable the existing telephone switchboard of 23 positions to be replaced by a modern suite of 38 operating and monitorial switchboards, while the automatic telephone equipment is being extended by apparatus capable of dealing with some 1,100 new subscribers. In addition, the new equipment will give further facilities for direct dialling by Banbury subscribers to a number of other nearby telephone exchanges.



Mechanics of Formation and Machine Shaping of Materials

Report on Investigations at M.E.R.L.

*The study of the properties and behaviour of materials when undergoing permanent deformation in such processes as extrusion, forging, rolling, on the one hand and machining on the other, is a function of the Plasticity Division of the Mechanical Engineering Research Laboratory at East Kilbride. The following account of some aspects of the work of the Division has been extracted from the Laboratory's Annual Report.**

THE manufacture of almost all metal articles involves plastic (permanent) deformation of the material. Most metalworking processes have developed largely by trial-and-error methods based on earlier production experiences, often without a full understanding of their mechanism. Systematic investigations are being carried out to provide a better understanding of the mechanism of plastic deformation so that economies in plant design and more efficient operation may be achieved.

The production processes involved fall into two groups: formation processes, such as rolling and forging; and processes such as milling and grinding where metal is removed. Both types of process are being investigated to determine the factors which govern plastic deformation in them. One aspect of the research on machining processes is to relate the wear of cutting tools to the mechanics of cutting.

To understand how metals deform in these processes it is necessary to know their plastic properties under the stress systems which occur in metalworking processes. The investigations include studies of plastic flow under combined stresses; the behaviour of materials under high hydrostatic pressure; and the effect on plastic properties of strain rate and temperature. If the plastic properties of a material are known, it may be possible to use the mathematical theory of plasticity to predict its behaviour in a metalworking process. This has been done for sheet drawing, and a single empirical formula has been derived for calculating the drawing stress.

Some industrial problems arise from non-homogeneity of the material. To explain why materials have certain properties it is necessary to consider the properties of the individual crystals of which the bulk material is composed. The theory of crystal plasticity is being applied to explain the behaviour of bulk materials in terms of the properties of single crystals. Almost all aspects of the strength and deformation of metals are governed by dislocations—defects in the otherwise regular spacing of atoms in a crystal—and special optical techniques for studying dislocations on crystal surfaces are being developed.

Design of Extrusion Dies

The dimensional accuracy and surface quality of an extruded product depend on the shape and surface finish of the die. Some preliminary investigations of the

effect of die shape on the extrusion pressure and temperature developed in the product have already been reported.^{1, 2} Further investigations are in progress to find out more about the effect of the shape of the die on the flow patterns during the extrusion of relatively simple symmetrical and non-symmetrical products. It is hoped that this may lead to a more rational procedure for designing dies for non-symmetrical products.

Tests have been made with cylindrical specimens, 1 and 2 in. in diameter, of lead, aluminium, copper, and brass. The metal flow was studied by splitting the specimens axially and inscribing a square grid on one of the parted faces; after extrusion the two halves were separated and the deformation of the grids examined. All tests were carried out with the metal specimens at room temperature, at punch speeds ranging from 1 to 28 in./min.

A die profile usually has three sections: an entry, which may be sharp-edged, radiussed or conical; a parallel section, or land; and a relieved exit. Relatively simple dies can be used for the extrusion of tubes and rods of circular, rectangular, hexagonal, elliptical, and other symmetrical sections, and there is a good deal of generalized information about metal flow through such dies. The additional tests have confirmed that, with many materials, lower pressures are needed for a given extrusion when the die has a conical rather than a straight-edged entry; a conical entry also reduces "piping"—the formation of a hollow region inside an extruded rod. With aluminium, however, higher pressures are needed with conical and radiussed entries, probably because aluminium tends to cold-weld on the face of the die. Radiussed entries have similar effects; altering the length of the land had little effect.

The extrusion of non-symmetrical sections requires considerable skill and experience from the die-maker; among other things he has to ensure a balanced flow through all parts of the die. The resistance to flow is greater in the narrower sections of the die, and if that is not allowed for, the product will be twisted or buckled. The flow of metal can be balanced by altering the shape of the die entry to obtain the required frictional conditions, and by altering the location of the die aperture relative to the axis of the billet being extruded. Similar balancing of the flow is necessary when extruding several sections through the same die.

As a preliminary to studying the flow through apertures of non-symmetrical section, the first series of investigations has been concerned with flow through

* "Mechanical Engineering Research, 1956," is published by H.M. Stationery Office for the Department of Scientific and Industrial Research. Price, 4s. (72 cents U.S.A.), by post 4s. 3d.

two-aperture dies. Most of the tests were made with a special die holder which enabled any combination of two dies to be mounted below a 2-in. diameter extrusion chamber; the distance between the die-aperture centres could be altered readily, and the position of the centroid of the apertures could be moved relative to the axis of the specimen. Dies with different entry profiles and different diameters of aperture enabled a wide range of extrusion conditions to be investigated.

When extruding simultaneously through apertures of different size, their centroid has to be displaced from the slug axis to obtain balanced flow, that is, products of equal length. Slugs of different heights were extruded through two sharp-edged apertures of different diameter, with the centroid of the combined apertures displaced from the slug axis by the amount required to give balanced flow. It was found that there was only a limited region in the middle of the slug where the flow of metal was reasonably uniform; this region was longer with the taller slugs. The flow patterns show that the extrusion of the initial and final parts of such a product is always under conditions favourable for twisting and bending. With the taller slugs, however, a greater proportion of the metal was extruded with balanced flow than with the slugs of lesser height, and the length of the two products was more nearly equal with the taller slugs.

The effect of the flow of a radiussed or conical entry to one of the die-apertures has also been measured. Both retard the flow more than a straight-edged entry and a conical entry is often used in practice to balance the flow.

The results so far, on the relatively simple case of simultaneous flow through two simple apertures, indicate the complexity of the problem, and further investigations are being carried out.

Plastic Properties Under High Hydrostatic Pressure

In metal deformation processes such as extrusion, rolling and machining, the flow of the metal is constrained in such a way that the deformation takes place in the presence of hydrostatic pressure which may be considerably greater than the yield stress of the metal. To simulate plastic flow under such conditions, mechanical tests must be carried out under high hydrostatic pressure. The effect of high pressure on plastic properties, such as stress-strain relations, yield stress, and ductility, is being investigated with two main objectives. Firstly, to obtain data which may help towards a better understanding of the way metals behave in formation processes; and secondly, to check the range of validity of the assumption, often made in mathematical theories of plasticity, that the yield stress of a material is independent of hydrostatic pressure.

The first stages in the development of apparatus for carrying out simple mechanical tests under pressures of up to 100 tons/sq. in. have been described earlier.³ The principle of the method for producing high pressure is to apply a relatively low pressure to the larger end of a differential piston; a high pressure is produced in a chamber at the smaller end, and held constant while tensile or torsion tests are carried out.

There has been further development of equipment with a high-pressure chamber of 1½-in. diameter bore, and an apparatus for making tensile tests inside this chamber. A simple Neoprene O-ring seal, backed with a

beryllium-copper mitre ring, has worked satisfactorily at pressures up to 100 tons/sq. in. Load gauges, consisting of a thin-walled steel tube to which foil-type strain gauges are bonded with a hot-setting adhesive, have been used repeatedly without failure up to the same pressure.

Tensile tests have been carried out on copper, aluminium, magnesium, zinc, Mazak (a zinc-base alloy), and cast-iron under a wide range of hydrostatic pressures.⁴ With all these materials there is a marked increase, as the pressure is increased, in their ductility (as measured by the strain which takes place before fracture). This fact is well known, and renders possible the large reductions in area obtained in extrusion and other formation processes.

Most of these metals necked considerably before fracture; with copper and aluminium at a pressure of 35 tons/sq. in. the specimens had necked so much that the area of fractured surface was too small to be measured. With copper, magnesium, and cast-iron the relation between ductility and pressure was approximately linear up to hydrostatic pressures of 35 tons/sq. in. Generally the increase of ductility with increasing pressure was gradual, but with zinc and Mazak there was an abrupt change from brittle to ductile behaviour for a small change of pressure, although the actual pressure at which the transition took place was different in different series of tests. To obtain repeatable results with Mazak and cast-iron, it was necessary to enclose the specimen in a rubber sleeve; it is thought that the sleeve prevented the high-pressure fluid from penetrating into any cracks which might form in the specimen.

When a tensile test is carried out under high pressure, an axial tensile stress is superimposed on the existing compressive stresses due to the hydrostatic pressure. Initially, therefore, the effect is merely to reduce the axial compressive stress on the specimen. The rubber-sleeved cast-iron specimens appeared to fracture under such a net compressive stress at hydrostatic pressures above 30 tons/sq. in. (the yield stress of the cast-iron used). This is difficult to understand, and further tests are to be carried out to see whether this unusual result can be explained by penetration of the rubber into pre-failure cracks.

Torsion testing under hydrostatic pressure has certain advantages over tensile testing but the experimental difficulties are much greater. Novel apparatus has been developed for this work (see Fig. 1). Essentially it is an electro-magnetic drive, a reduction gear-box, the specimen, and a load cell. The whole apparatus is only 8 in. long and fits inside the 1½-in. diameter pressure-chamber. It has not yet been used under pressure, but it works successfully in a viscous oil and will twist a mild-steel specimen, 0.1 in. in diameter, to failure. It is hoped to test it soon under high pressure and to carry out torsion tests on a range of metals.

Anisotropy of Polycrystalline Aggregates

When metals are deformed in formation processes they develop directional properties, peculiar to the process involved, which may affect the quality of the product. Variation of strength in different directions resulting from primary processes like rolling is particularly important, as it is responsible for many of the problems which may arise in subsequent mechanical working. For example, cups drawn from rolled sheet may develop "ears" which have to be machined off. A



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Device for torsion testing under high hydrostatic pressure.

theory has been developed which enables the variation of strength with direction to be calculated for certain metals.

Engineering metals are normally composed of a large number of single crystals, each of which has a regular atomic structure. If the directions of the crystal axes are randomly distributed, the material has the same strength in all directions and is said to be (mechanically) isotropic. When a polycrystalline material is plastically deformed, each grain is distorted and the crystal axes rotate in a systematic manner. The crystal axes tend to be aligned in certain directions rather than others. The yield strength of the deformed bulk material will vary with direction as it depends on the orientation of the crystals as well as on their strength.

The plastic properties of an initially isotropic aggregate of crystals of a face-centred cubic metal such as aluminium, copper, and lead can be calculated by using the Bishop-Hill theory of crystal plasticity⁵; the yield stress of a polycrystalline aggregate is calculated from the known properties of single crystals, using an averaging process to take account of their orientations. In principle, the Bishop-Hill theory could be modified to permit the calculation of the plastic properties of an anisotropic aggregate, but this would involve a tremendous amount of computation. The new theory⁶ therefore starts with deformation textures, obtained by X-ray methods, which give a measure of the alignments of the crystal axes.

When these face-centred cubic metals are deformed in processes like wire and strip drawing, and sheet rolling, anisotropy develops. The onset of yield for isotropic aggregates of these metals closely follows a mathematical expression usually attributed to von Mises; it is assumed that the yielding of an anisotropic aggregate can be represented by the same form of criterion, suitably modified in accordance with the observed deformation textures, using an averaging process to take account of the different numbers of crystals aligned in various directions.

The variations of yield strength with direction resulting from the uniaxial compression of aluminium, copper, and brass have been worked out. One interesting conclusion

is that in brass the variation is much greater than in pure copper. It is hoped to apply the theory to the anisotropy of sheet metals, as this may explain how cracking and tearing arise and how they may be prevented.

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Stainless Steel Wind Tunnel

THE sixth large wind tunnel to be constructed at the Royal Aircraft Establishment, Bedford, is now nearing completion. The test section of the tunnel, designed to work at up to 16 atmospheres absolute and to reproduce actual flight conditions at continuously varying speeds ranging from Mach 2.5 to Mach 5, is constructed almost entirely from stainless steel.

A special feature of this new supersonic wind tunnel is that provision is being made for operating at stagnation temperatures up to 150° C. in order to avoid partial liquefaction of the air in the working section at the higher Mach numbers. Because of this, and the very high skin temperatures resulting from frictional heating at the higher speeds, the low alloy steels previously used for some of the earlier and lower speed tunnels were ruled out in this instance because of inadequate surface protection.

The steel used for the new tunnel is F.I., a 40-ton 13% chromium stainless steel manufactured by Firth-Vickers Stainless Steels, Ltd., of Sheffield. It has been supplied in plates 27 ft. long by 3 ft. wide and 2½ in. thick prior to machining. The most notable application will be for the flexible floor and roof plates, which will be operated between the side walls by means of servo-controlled, electrically operated jacks to achieve continuous variation of air speed.

New Metallurgical Laboratory for B.W.R.A.

Opening Ceremony
performed by
Lord Tedder



The entrance to the new metallurgical laboratory.

FOR some years, the laboratory facilities of the British Welding Research Association have been divided between the London headquarters, at 29, Park Crescent, and Abington Hall, near Cambridge. The first research sections established at Abington were those concerned with engineering aspects, the metallurgical work being carried out in London. With the completion of the new Metallurgical Laboratory, which was opened by Marshal of the Royal Air Force, the Rt. Hon. the Lord Tedder, G.C.B., D.C.L., LL.D., on July 23rd, the research activities are now concentrated at Abington, the only sections of the Association remaining at Park Crescent being those concerned with development, administration and publications.

The new building has a welded portal frame structure designed in accordance with the plastic theory developed by Professor J. F. Baker at the University of Cambridge,

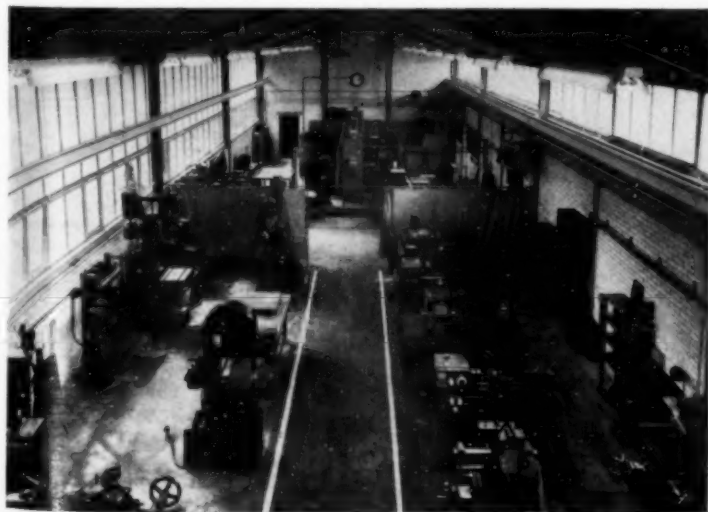
with financial support from the Association. The welding laboratory, which is housed in the new building, is equipped for manual and automatic welding. A specially designed instrument panel enables the welding variables to be measured and recorded automatically in an observation room from which the progress of welding operations can be followed. Provision is made for research on the welding of reactive metals, and on heat flow in welding. There are also well equipped laboratories for chemical and gas analysis, metallographic examination, heat treatment and mechanical testing.

Welding Laboratory

The welding laboratory contains a comprehensive range of equipment for the metal-arc and gas-shielded welding processes. Extensive use is made of automatic traversing units, as these permit better control of welding conditions than can be obtained with manual welding. A large traversing unit to be used in conjunction with both the controlled tungsten-arc and inert-gas metal-arc welding heads, capable of a speed range of 2-500 in./min., is under construction.

Power supplies for the welding equipment are brought in by overhead busbar, and take-off points are provided on three stanchions in the centre of the floor area. All equipment is connected via standard plugs, so that the various units are readily interchangeable. Welding power sources include commercial transformers, transformer-rectifiers, and motor generator sets with capacities from 25 to 750 amp. An experimental variable characteristic generator is also available, and a 1,000 amp. battery supply is being installed.

The working area in the laboratory is divided into four principal bays, which are so arranged that the centre two can be viewed from the window of the



General view of the machine shop with the welding laboratory in the background.

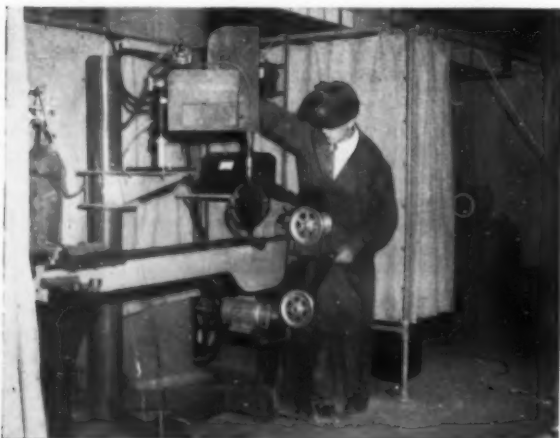


Manual welding bay in the welding laboratory, showing the observation window of the instrument room, simple positioner table, 21F Argonaut and Sigma SWM2 welding equipment.

instrument room. Manual welding is normally carried out on a simple positioner table in front of this room. In this location observation of welding can be made behind the tinted glass windows, and the instruments are housed in satisfactory conditions.

In work on the hot cracking of steel weld metal, both high temperature tensile testing of weld metal and hot cracking tests on welds have been carried out. For the latter, a Murex hot-crack machine is available, in which a fillet weld is deposited between two plates which are rotated mechanically to apply strain to the weld metal. Recent work has shown the importance of the Mn/S ratio.

Welds made in aluminium by the self-adjusting arc process at currents of more than 350 amp. contain large voids and oxide folds, a feature which is a serious limitation in an otherwise satisfactory process for automatic operation. The Association has shown that, by controlling the ingress of air to the arc and weld pool at high currents, these defects may be overcome. A special



Controlled tungsten-arc welding equipment set up for circumferential welding.

nozzle has been devised which has been used to produce satisfactory deposits at currents up to 600 amp.

Equipment for controlled tungsten-arc welding, obtained with the help of American Co-operation Administration funds, enables the torch to follow automatically an uneven contour in the work piece. Control is by the arc voltage through an electrically operated actuator, which raises or lowers the head to keep a constant arc length.

Instrument Room

Mention has already been made of the instrument room, which provides a vantage point where measurements of welding variables may be made away from the glare of arcs, fume and spatter. Slots are provided in the walls, through which welding cables and instrument leads may be passed. Instruments available include a universal recording and indicating unit for welding time, current, and voltage; a high speed temperature recorder used for measuring the thermal cycle in heat-affected zones; oscillographic equipment for recording welding voltage and current; and furnace control equipment specially arranged for maximum flexibility in use.

The behaviour of welding arcs and the influence of electrical parameters on the metallurgical properties of the weld bead is a study of particular importance in dealing with the gas-shielded welding processes, which are undergoing rapid development. Work on arc characteristics is being carried out in co-operation with the Electrical Research Association and interesting results have been obtained on the aluminium self-adjusting arc and carbon-dioxide shielded arc processes.

Reactive Material Welding

The welding characteristics and properties of titanium and zirconium alloys are being investigated, and special problems in welding reactive metals in the "open-air" are also being examined. These metals are readily contaminated by traces of oxygen, nitrogen and hydrogen, and the properties of welds entirely free from contamination are obtained from test welds made in a chamber which can be evacuated to 10^{-5} mm. Hg. and filled with high purity argon. Material for welding may be annealed or treated for hydrogen removal in a vacuum annealing furnace designed to work up to $1,000^{\circ}\text{C}$ at 5×10^{-5} mm. Hg. An autoclave has been acquired for the corrosion testing of zirconium alloy welds in high temperature water or steam.

"Open-air" welding equipment comprises a traversing table with a speed range of 0-70 in./min., perforated backing bars, torch and mechanised wire-feed unit. The effect of argon velocity, nozzle diameter, and nozzle-work distance on the area of shielding has been investigated for round nozzles. An improved nozzle with trailing shield suitable for manual welding has been devised and is under test.

Alloy Steel Weldability Testing

Two important and related aspects of weldability are the heat-affected zone cracking of alloy steels and the cold cracking (or fissuring) of weld metal. The B.W.R.A. long plate test is being used to investigate both these aspects. Bead runs are laid on a plate approximating to infinite heat sink conditions. Plate thickness and electrode size are used to vary the cooling rate of the weld bead, from which sections are cut and examined for cracks and fissures. The effects are rather complex, as a

decrease in cooling rate due to using a larger electrode tends to reduce the number of fissures, while the increasing size of the deposit tends to increase fissures by generating higher stresses.

Heat affected zone cracking is studied in various ways, including the now well-established C.T.S. test. In a recent modification of the technique, economy in the material under test is effected by using inserts of the test material in a mild steel block. This technique is useful when only limited quantities of a special steel are available for test.

Previous work by the Association showed that the transformation temperature of a steel gives a useful indication of weldability, and a rapid action dilatometer has been developed for its determination. A small sample of the test steel is placed in the dilatometer and heated in a high frequency induction coil, then quenched in a stream of argon to simulate the cooling cycle in the heat-affected zone. The dilation-temperature record is plotted directly on a special recording instrument. A time-temperature curve is plotted simultaneously with the dilation, the whole forming a complete record from which the transformation temperature may be estimated.



Rapid action dilatometer for determining transformation temperatures.

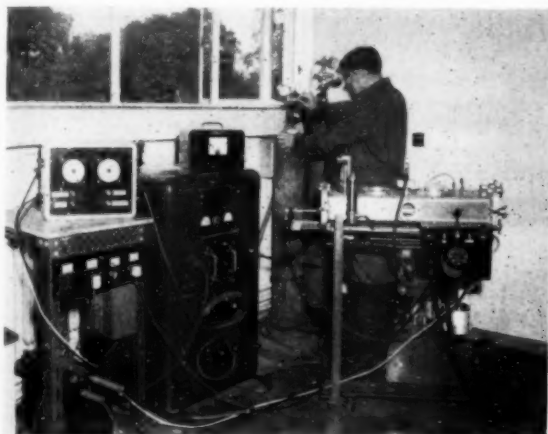
The gases evolved are analysed by the successive removal of each gas, and hydrogen, nitrogen, oxygen, carbon-monoxide, and other combustible gases may be estimated.

General Laboratory

The general laboratory houses the mechanical testing equipment and other apparatus of common interest to the various research groups. Apart from the normal tensile impact and hardness testing machines, there are a number of creep testing machines.

A furnace is available in which materials may be tested at elevated temperatures *in vacuo* or in an inert atmosphere. Heating is effected by a platinum winding, and tests have been carried out up to 1,450° C. The furnace was designed in the first place for an examination of the ductility of weld metal at elevated temperatures, as part of a programme of research on the hot cracking of weld metal. It was hoped to relate the dip in the ductility-temperature curve, which occurs at about 1,000° C., to the tendency to hot cracking.

A limited amount of work has been carried out on filler materials for high temperature brazing, and on the



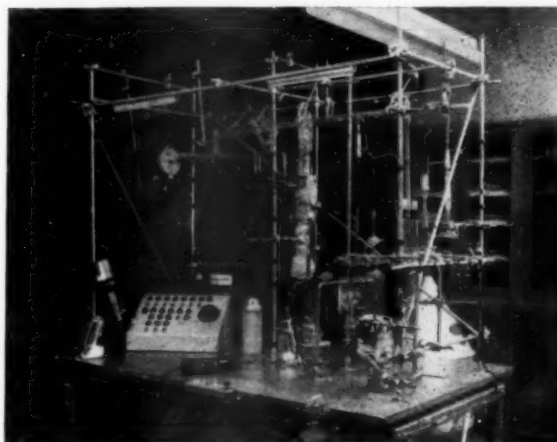
Welding chamber, vacuum pumps, welding equipment and instruments in the reactive metal laboratory.

Gas Analysis

Greatly improved facilities are now available for both chemical and gas analysis. Because of the importance of gases on the properties of welds and welded joints, considerable attention is devoted to the extraction and analysis of gases present in various forms. For example, a method is at present being developed for the identification of gases occurring within voids in weld metal. The sample containing the voids is contained in a vacuum chamber and fractured in a tensile testing machine. The gases evolved are collected and analysed qualitatively.

Hydrogen is known to play an important part in both weld-metal and heat-affected zone cracking in alloy steels, and a method has been devised whereby the hydrogen trapped within a weld bead on solidification, and available for diffusion, may be estimated by quenching a sample weld bead, immersing it under mercury and measuring the hydrogen which diffuses out.

A versatile apparatus now available can be used for the hot extraction of gases in metals or, with simple adaptation, for the tin fusion gas analysis of light alloys.



Low pressure gas analysis apparatus.



Part of the heat treatment room.

strength of joints at elevated temperatures. Specimens brazed in hydrogen in a high frequency induction-heater

are submitted to stress rupture tests at 650° C. in a 1-ton creep testing machine. The melting behaviour of a filler alloy is assessed by brazing discs spaced apart by 0.002, 0.005 or 0.010 in. After brazing, the upper disc is machined away to reveal the filled area of the joint.

Metallography Section

The metallography section is housed in a preparation room, a microscope room, a dark room and an office. A comprehensive range of optical microscopes is available, which includes a Reichert Metallograph for photomicrography up to $\times 2,500$, a Reichert Zetopan binocular bench microscope (both these instruments are fitted for phase contrast and polarised light examination), a Vickers projection microscope, and a Kentron microhardness tester.

Heat Treatment Room

This houses seven furnaces for high and low temperature heat treatment, which are wired to the control panel in the instrument room, and two small furnaces capable of melting most non-ferrous metals. Wire drawing equipment is also installed in this room: this is used in the preparation of experimental types of filler wire.

Translator Control

A New Method of Controlling Electrical Plant

WHERE several electric drives have to be co-ordinated, as in a rolling mill, a large amount of electrical equipment is required. In conventional installations, the operator controls switches, push-buttons, etc., and these control many relays, which are interconnected to provide the correct sequence of operations. Some of the relays are thus controlled by the plant itself (limit switches, for example). The "instructions" that the operator sends consist of low-power electric signals, and the only function of the relay gear is to translate his low-power instructions into control signals at the required power level.

Conventional relay gear does this somewhat clumsily

and at considerable expense. The translator control, developed by B.I.S.R.A.'s Plant Engineering Division, to perform many of the functions of traditional relay gear is not only simpler, cheaper, and more compact, but it saves the operators much routine operation of switches. The input to the translator, which is a "packaged unit," consists of information about the material and process required; the output consists of automatic instructions to the plant in the form of electric signals.

Rolling mills, skip hoists, flying shears, and saw benches are among the many types of plant in the iron and steel industry to which translator control can be applied. The larger and more complex the equipment

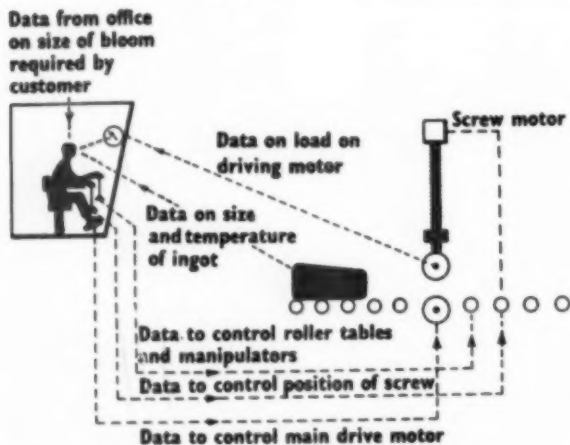


Fig. 1.—Data handled by the operator of a primary blooming mill.

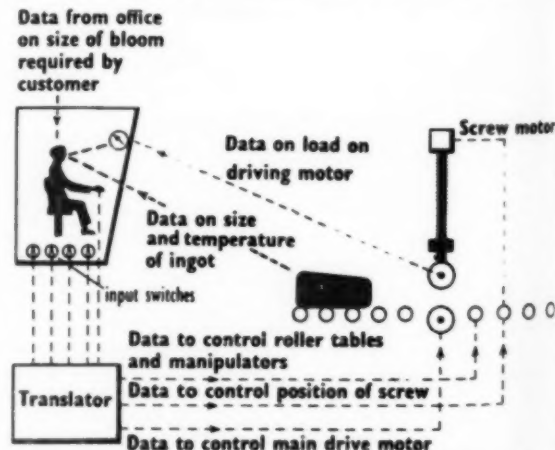


Fig. 2.—Primary blooming mill equipped with translator control.

to be controlled, the greater the benefits to be obtained by using this new control system.

Translator control is best described by referring to a specific example, such as a primary rolling mill. Fig. 1 illustrates the functions of the operator in a typical present-day primary blooming mill. Information on the size of bloom required by the customer comes to the pulpit from the office, and the operator himself collects more data by observing his instruments and noticing the appearance of the ingot. He then goes through a programme of main drive and auxiliary movements appropriate to this data. The translator can perform the function of handling this data and will remove much of the routine work.

If the same mill were equipped with a translator control similar to that already developed by B.I.S.R.A., the arrangement would be as shown in Fig. 2. The operator would then have four switches on which he would set (i) the weight of the ingot, (ii) and (iii) the final dimensions (height and width) of the bloom to be rolled, and (iv) the number of passes (which would depend largely on the temperature of the ingot). He would also have three push-buttons, labelled "insert data," "next pass" and "reset." The "reset" button would only be pressed in the event of the rolling of an ingot being abandoned. When the ingot arrived he would check the settings on the four switches and if any changes were required, would make them and press the "insert data" button. The translator control would then send to the mill electrical signals to operate the screws, manipulators, and tilt fingers and the mill would be ready for the first pass. Pressing the "next pass" button after each pass would then cause the appropriate further instructions to be sent to the mill. When the "next pass" button was pressed after the final pass, the translator would automatically send to the mill the instructions for the first pass of the same rolling schedule. It would do the same if at any time during rolling the "reset" button were pressed.

How is all this done? It will be apparent that the information supplied by the operator with his four switches and "next pass" button is sufficient to specify the entire rolling schedule—screwdown settings, tilting and roll-hole. When the translator receives from the control desk the information supplied by the operator, it relates it to one of the rolling schedules stored in its "dictionary." The "dictionary" will normally hold up to 150 different rolling schedules, but this number could be greatly increased if necessary. The equipment is constructed from motor uniselectors and relays such as are used in telephone exchanges, and the total cost is so low that it is quite feasible to provide a complete spare translator unit to ensure the rapid replacement should any faults occur.

In the control described above, the one choice left with the operator in which an error of judgment might be made is the number of passes. If he makes a mistake, the load on the main drive of the mill will be either too great or too small. This possibility could be avoided by arranging for the mill motor loading to be displayed to the operator, or, in a more advanced scheme, a load relay in the motor circuit might be arranged to send a signal to the translator so as to change the schedule if necessary after the first, or perhaps the second, pass. "Closing the loop" in this way would cause the translator to change the schedule according to the circumstances, instead of continuing with an inappropriate programme. By extending this self-regulating principle further and

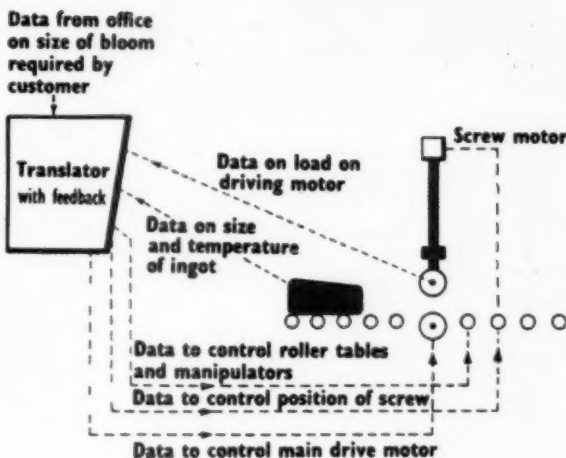


Fig. 3.—Completely automatic blooming mill controlled by translator.

monitoring the mill continuously with signals fed back from the drive to the translator, the primary mill could be made completely automatic. Rolling would then progress according to the instructions from the office, and from the mill itself, fed directly into the translator, as shown in Fig. 3.

The translator control equipment is now being developed commercially.

Aluminium Subway Car Film

A NEW 16 mm. film, "Light-weight Trains for Toronto," was presented for the first time before an invited audience at the offices of the Aluminium Development Association on Thursday, August 1st, 1957. The film, produced in collaboration with the Gloucester Railway Carriage & Wagon Co., Ltd., and the Toronto Transit Commission is in full colour with running commentary. It opens with a brief impression of the Toronto subway, and then moves immediately to the genesis of the project in the design office. The main part of the film is taken up with the production history of the aluminium car as it goes through the works, with diversions to the foundry at which the sliding doors were sand cast, and to an extrusion plant. The last shots in this sequence show the exterior of the finished, unpainted, cars being coated with lanolin, and windows and doors being boarded, for transit as deck cargo across the North Atlantic. Closing scenes are from the Canadian side, giving a variety of impressions of these cars—both on the surface and in the subway—at speed, moving off, and braking. The film, which is available for loan, runs for approximately 20 minutes.

Fielden Branch at Stockton

FIELDEN ELECTRONICS, LTD., announce the opening at the beginning of September of the new North Eastern Sales and Service Office at Stockton-on-Tees. The branch is under the management of Mr. K. HYMER, who is well known as the Company's representative in the North East. He is now supported by experienced service engineers in this area.

Furnaces for the Aluminium Die Caster

Two New Units Available

Electric Maintaining Furnace

TWO well-known furnace manufacturers—The Morgan Crucible Co., Ltd., and Birlec, Ltd.—have collaborated in the design and production of a new furnace specially designed for the aluminium die caster. Known as the Birlec-Morgan electric die casting furnace (Type EDF, Mark I), it is a 300 lb. (135 kg.) electrically heated crucible furnace for maintaining aluminium and aluminium alloys. It thus combines the proved advantages of crucible melting with the benefits of electric heating and automatic control.

The Furnace

The lining of the furnace comprises an outer layer of insulating slabs, two inner layers of refractory insulating bricks, and a hot face of moulded refractory bricks forming element carriers. The heating elements are nickel-chrome alloy wire, in coil formation, with lead-out rods through the furnace brickwork to external terminals, which are provided with a ventilated guard. The metal is held in a crucible and a foot-operated insulated cover is provided to reduce heat loss and operator fatigue: alternatively, a hand-operated cover is fitted.

Control Gear

The fully-automatic temperature control gear is housed in a self-contained floor mounting cabinet. Control is of the on-off type, and is actuated by a continuously immersed thermocouple protected by a mullite-silicon carbide composite sheath. The temperature indicator-controller is of millivoltmeter type, and a "pyrolimit" indicator is fitted to prevent the elements rising above a safe temperature, the thermocouple being in the lower part of the furnace chamber. Both instruments have a broken thermocouple safety device, and manual operation is provided against instrument or couple failure,

over-riding the auto-control gear, but not the element safety device. A time switch can be provided to switch on the furnace at a pre-selected time, so that it can be started up early morning and be ready for use at the start of the working day.

Performance

The Type EDF has a rating of 25 kW., and is suitable for maintaining the metal temperature at up to 800° C. To maintain 300 lb. of aluminium at $720 \pm 5^\circ \text{C}$. requires 9 kW. input, and with a full rating of 25 kW. a maximum working throughput of 80 lb./hr. is possible at 720° C.; removing 10 lb. of molten metal and charging 10 lb. of solid metal at 8-minute intervals gives a temperature fluctuation of 15° C.

The automatic control of the heating ensures constant performance from the furnace. In this way a controlled casting temperature is maintained and variations in metal quality are avoided. A further advantage is that the operator has no need to worry about the metal, and can devote full attention to the casting operation.

Oil-Fired Melting Furnace

The Morgan Type BT Mark II basin tilter is an oil-fired crucible furnace of 380 lb. (170 kg.) capacity, designed as a feeder for maintaining furnaces, and is, thus, complementary to the Type EDF. It has a high melting rate, simple comfortable operation, and lip pour.

The Furnace

The unit is lined with Tri-Mor high temperature castable refractory, backed with insulating brick—a combination designed to ensure cool working conditions, high



Type BT basin tilter oil-fired melting furnace.



Type EDF electric die casting furnace.

performance, and maximum life. Spare bodies are available so that the furnace in production can be changed with minimum delay. The basin-shaped Salamander crucible facilitates charging ingot or scrap, and supercharge preheating is incorporated: where flame contact must be avoided for metallurgical reasons, however, a muffle ring is available.

A special feature of the basin-tilter is the built-in hydraulic tilting mechanism. This gives smooth lip-axis pour with finger tip control and a steady pouring point, enabling ladles to be kept in one position throughout the pour. Specially designed hydraulic rams obviate the necessity for excavating deep ram pits. As a modern spilt metal tray replaces the conventional pit, the furnace is completely floor mounted and does not need excavation work prior to siting.

Flame Cleaning

An Effective Preparation for Painting

THE protection of steel surfaces from rust and corrosion is one of immense importance, as the annual loss of steel throughout the world, as a result of corrosion, amounts to many millions of tons. Research organisations are constantly attempting to discover improved methods of preserving steel against atmospheric and salt water corrosion, and a number of specialised coatings have been developed. It should be emphasised, however, that the surface must be suitably prepared before applying the coating, as rust, once established, will continue to grow under the best of coverings.

Even a thorough wire brushing is not entirely satisfactory to prepare a rusted surface for painting, as the slightest film of moisture or other incompatible material on the metal will prevent satisfactory bonding of the base coat and permit corrosion to continue after the coat has been applied. The most commonly used preparation is hand or mechanical chipping, followed by wire brushing. Other methods, such as grit or sand-blasting, pickling and phosphating, are to a large extent limited or impossible on site. Chipping, although it has been favoured for a long time, raises burrs, whose sharp edges make it difficult to obtain the desired paint thickness. Again, chipping will not get into the many pockets of rust.

Method of Operation

A process which has been in use for a number of years is featured in a new industrial film issued by British Oxygen Gases, Ltd., who introduced the process to this country. In brief, the process consists of passing a high temperature flame over the surface of the metal in a series of $\frac{1}{4}$ -in. forward $\frac{1}{4}$ -in. backward movements. The operation is facilitated by providing the blowpipe with suitably shaped nozzles, e.g., flat nozzles which give a brush-like flame pattern for flat surfaces and large areas, and round nozzles for small sections and awkward corners.

The oxy-acetylene flame which is normally used has the effect of warming the steel so that no moisture is present, thereby removing the prime cause of corrosion. Moreover, the passage of the flame over the surface

Firing

The furnace is fitted with a Morgan Type LST Mark II low pressure burner, which ensures a fixed firing line which cannot drift, but has been so designed that it can be easily swung away to allow inspection of the firing tunnel. Air is required at a rate of 250 cu. ft./min. at a pressure of 25 in. W.G. A 4-in. air pressure gauge is fitted, which is calibrated so that it can be used as a burner control guide as well as an air pressure indicator.

Performance

With the first heat of the day, it takes 50 minutes to melt 380 lb. of aluminium and heat it to 720° C.: for subsequent heats the time is reduced to 30 minutes. Using fuel of 200 sec. Redwood No. 1 viscosity at 100°F. and 176,000 B.Th.U./gal., the consumption for subsequent heats is 4.6 gal. per heat.



Operating a flame cleaning torch.

causes differential expansion between mill scale and steel, so that most, if not all of the scale becomes detached. Any mill scale remaining is so firmly bonded that, provided it is protected from moisture, it will remain inert and is not likely to become detached. Besides removing loosely bonded scale, the flame dehydrates the rust, leaving it as a dry powdery deposit easily removed by wire brushing.

The absorbed heat has a three-fold function: (a) it eliminates surface moisture, thus preventing further corrosion; (b) it allows the paint to flow more readily into pits and crevices, giving a good mechanical bond; and (c) it also speeds up the drying of the paint, making possible the application of two coats in any one day. In this country, where so many damp days are experienced without actual rain, the flame cleaning process permits

painting when otherwise it would be impracticable—an important point when staging and other considerations are involved.

Applications of the Process

The film, which is in full colour, features sequences illustrating typical applications of the process, such as shipbuilding, constructional engineering, and hydraulic engineering. The potentialities of the process have been recognised for a number of years by shipowners and shipbuilders. The storage, fabrication and construction of steel plate into ships' hulls are all factors which promote the spread of corrosion long before launching, as well as increasing the time spent on overhauls. After an area has been flame-cleaned, it is wire brushed to remove the oxide dust, and then painted while the steel is still warm. Scaffolding erected for the construction of the vessel ideally suits the requirements of the flame cleaning operators, as no additions or alterations are necessary. Where a continuous flow of work is essential for the economy of the operation, the benefits of quick drying and of being able to apply two coats in one day are readily appreciated. No unsightly roughness is left, and a glossy smooth skin is an important factor in the attainment at sea of maximum speed with minimum fuel consumption: furthermore, less time is spent in dock for periodic cleaning.

Harbour buoys, awash for years in sea water, also

require continuous protection. The buoys are freed of marine growth and heavy corrosion by mechanical means, for economy of gas, and are then flame cleaned, wire brushed, and painted. Up to nine coats of paint may be applied to those parts of the buoy which are to be totally immersed, and inspection during service shows the increased protection afforded when flame cleaned prior to painting.

Those responsible for public highway maintenance use flame cleaning on various types of steelwork, including bridges. Damp mists are not unusual in areas in which electricity grid pylons are situated, and here, too, flame cleaning can be shown to have advantages, including portability and the ability to carry out the work in the very limited time allowed for the necessary interruptions of power supplies.

Many miles of hydro-electric pipeline, mostly in inaccessible places, are successfully flame cleaned after erection. No trace of mill scale or rust is permitted to remain before painting. Apart from corrosion protection, the abrasive action of the continuous flow of thousands of gallons of water is reduced, and the smoothest possible passage is achieved, with the aid of the process.

The Company claims, not without justification, that recognition that the cause of corrosion—moisture in all its forms—can be eliminated and its recurrence minimised with the aid of the oxy-acetylene flame, will lead to increased life and less frequent overhauls.

Speedier Furnace Dismantling

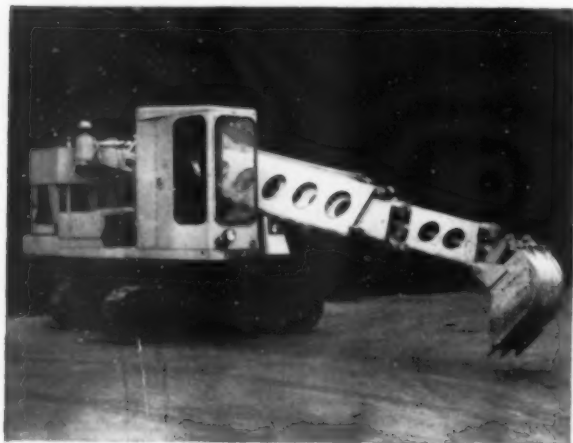
OPEN hearth furnace dismantling time is being cut by two days following the introduction of a powerful excavator at the Rotherham works of Steel, Peech and Tozer, a branch of the United Steel Cos., Ltd.

Known as a Gradall, this £11,000 American-built machine is mounted on crawler tracks and is equipped with a telescopic boom at the end of which either a hook attachment or a bucket can be fitted. When the brickwork of a furnace becomes due for dismantling, the hook attachment is first employed to claw away the old bricks; then the hook is replaced by a $\frac{3}{4}$ cu. yd. bucket which scrapes the brick debris out of the furnace bath. Dismantling can begin within five or six hours of tapping a

furnace, compared with the 24 hours which must elapse before men can enter the furnace to do the work manually.

The Gradall is being employed on the removal of bricks above furnace stage level—the roof, ends, front and back walls and part of the uptakes—in the company's Templeborough melting shop. This shop contains 14 100-ton open hearth furnaces, of which 12 have hitherto been in operation at any one time. Because of the speedier dismantling, it has now become possible to operate up to 13 furnaces on occasion, with a corresponding improvement in steel output.

The machine weighs 13 tons and is driven by a 75 h.p. diesel engine. Both the crawler mechanism and the telescopic boom are hydraulically operated. Time taken to change the boom head from hook attachment to bucket is about ten minutes.



The Gradall excavator.

Pure Boron Available

BORAX CONSOLIDATED, LTD., (Borax House, Carlisle Place, London, S.W.1.) are marketing crystalline elemental boron in the pure state (99.0% to 99.7%), which is expected to be of great interest to the electrical and metallurgical industries, and also for certain nuclear energy applications. In December, 1955, the company announced pilot-scale production of two grades of amorphous elemental boron, one in 90%-92% and the other in 95%-97% purity, and since then they have been working towards the production of the pure element. The new product is far more inert than the finely divided amorphous material, and has a low oxygen and nitrogen content, making it particularly suitable for incorporation into alloys.

NEWS AND ANNOUNCEMENTS

Postgraduate Courses in X-Ray Crystallography

POSTGRADUATE courses in X-ray crystallography leading to the examinations for the degree of M.Sc. of the University of London or the postgraduate diploma of the Battersea College of Technology, D.C.T. (Batt.), will be held in the Metallurgy Department of the College, commencing in September, 1957. The courses will be staffed by specialists in individual subjects.

The minimum duration of the courses will be one session for full-time students or two sessions for part-time students, but provision is made for attendance at lectures or practical classes in individual subjects of the course. The entry qualifications to the courses will be those laid down by the University of London or the College of Technology respectively.

The courses are designed to cover a general syllabus in X-ray crystallography with an emphasis on applications in metallurgy. The syllabus is the same for both courses and includes symmetry theory, stereographic projection, theory of X-ray diffraction methods, crystal physics and optics, crystal chemistry, structure analysis and crystallography of metals. Advanced topics will include electron and neutron diffraction. Practical work includes use of the various types of X-ray generators and diffraction cameras, the polarising microscope and other modern metallurgical techniques.

Further particulars can be obtained from the Head of the Metallurgy Department, Battersea College of Technology, Battersea Park Road, London, S.W.11.

Institute of Metals Autumn Meeting

THE Institute of Metals Autumn Meeting is this year being held in Glasgow, from September 16th to 20th. Two technical sessions have been arranged; on the morning of Tuesday, September 17th, commencing at 10 a.m., there will be a discussion on creep, based on five papers previously published in the Institute's *Journal*; and on Thursday, September 19th, commencing at 9.45 a.m., there will be an informal discussion on the use of light alloys in ship construction, arranged by the Metallurgical Engineering Committee. The programme includes a number of social functions, and a series of visits to works and places of interest in the Glasgow-Edinburgh area.

Materials Handling Convention

THE Materials Handling Group of the Institution of Production Engineers have arranged a three-day Convention, to be held at Leamington Spa from Monday, 28th October, to Wednesday, 30th October, 1957.

The programme includes visits to factories in the Leamington and Coventry areas to see materials handling developments connected with specific problems: these visits will be followed by discussions in syndicates and group reports. Delegates will be divided into parties of 15-25 for the purpose of these visits and discussions: subjects at present listed include handling of bar in long lengths; handling of swarf; handling of small components; introduction of mechanical handling methods into a small factory employing fewer than

fifty persons; the mechanised foundry; handling of loose bulk material; materials handling in a modern bakery; handling problems created by the introduction of transfer mechanisms; and case study in collaboration between architect and production engineer in design of new building. A paper on "The Mathematics of Handling" will be presented on Wednesday afternoon by Dr. K. D. Tocher, Research Applications Manager, Department of Operational Research and Cybernetics, The United Steel Cos., Ltd.

The Convention fees are six guineas for members of the Institution and seven guineas for non-members, except that participants in materials handling courses organised by technical colleges will be charged at members' rate. Application forms should be returned as soon as possible to the Secretary, the Institution of Production Engineers, 10 Chesterfield Street, London, W.1.

Flames and Industry Symposium

THE proceedings at the one-day Symposium on Flames and Industry, to be held at the Institution of Civil Engineers, Great George Street, London, S.W.1, on October 9th, will be opened by the President of the Institute of Fuel, Mr. J. R. Rylands. Professor O. A. Saunders will take the Chair at the morning session, and Dr. D. T. A. Townsend in the afternoon.

The papers presented will deal not only with further results of research on flame radiation, but also with the significance in practice of these results in various industrial applications. These will be treated in separate short papers to be discussed in the afternoon, the morning being devoted to an opening paper on flame research and one on the application in industry of experimental techniques used by the International Flame Research Foundation. Papers dealing with heat transfer from flames will also be given, as applied in the various industries: steel, glass, cement and oil; and in boilers, gas turbines and furnaces generally.

Enrolment forms and advance sets of papers may be obtained from the Secretary, the Institute of Fuel, 18 Devonshire Street, Portland Place, London, W.1; any further details, or enrolment forms only from the Secretary, British Flame Research Committee, 11 Park Lane, London, W.1. (Tel: Grosvenor 4751).

Symposium on Polarography in Industry

THE Polarographic Society is organising a Symposium on Polarography in Industry, to be held in London on October 24th-25th, 1957. Papers submitted cover a wide range of subjects including automation, trace analysis, etc. Speakers include overseas personalities of international standing. Further details can be obtained from the Symposium Secretary, G. Russell, Esq., F.R.I.C., 15, Weald Close, Brentwood, Essex. Applications must be completed by September 30th.

Change of Telephone Number

THE telephone number of B.K.L. Alloys, Ltd., has been changed to Kings Norton 4231 (8 lines).

Copper Pass Awards

THE Adjudicating Committee, representing the Councils of the Institution of Mining and Metallurgy and of the Institute of Metals, have made the following Copper Pass Awards in respect of papers published in the *Transactions* of the Institution of Mining and Metallurgy and the *Journal* of the Institute of Metals for the year 1956.

£120 to DR. J. M. FLETCHER, DR. D. F. C. MORRIS and MR. A. G. WAIN for a paper on "Outline of a Solvent Extraction Process for the Purification of Niobium from Ores or from Ferro-Niobium."

Fifty Guineas to MR. J. A. GRAINGER for a paper on "The Deep Drawing and Spinning of Sheet Metal, with Particular Reference to Non-Ferrous Materials."

Fifty Guineas to MR. J. FIELDING for a paper on "Rubber Pressing."

These Awards are made from a fund placed at the disposal of the Councils of the two Societies by the Directors of Copper Pass and Son, Ltd., for the encouragement of the publication of scientific and technical papers dealing with processes and plant used in extraction metallurgy and on the subject of assaying and of papers on processes used in all branches of the non-ferrous metal industry.

Air Pollution in the Iron and Steel Industry

A TWO-DAY Meeting on Air Pollution in the Iron and Steel Industry, organised by the Engineers Group of the Iron and Steel Institute, will be held at Church House, Westminster, London, S.W.1, on Wednesday and Thursday, September 25th and 26th, 1957. Papers will be presented by authors from Austria, France, Germany and the United States, as well as from the United Kingdom. The Meeting will be open to all those interested, whether members of the Iron and Steel Engineers' Group or not.

Non-Destructive Testing Course

ENCOURAGED by the results of a similar venture in 1956, the British Council is organising a course on the non-destructive testing of materials in February, 1958. The course is intended for overseas industrial technologists and university research workers in science and engineering and will be limited to fifteen members. Course members will be accommodated in centrally situated hotels, and the fee for the course is £42.

The course will consist of a series of lectures, discussions and visits. On this occasion the main emphasis will be on the scientific background of non-destructive testing, and the method of treatment of this aspect of the subject has been so chosen as to show the progress which is being made by industry in employing relevant scientific knowledge for establishing systems of quality control and for developing automatic processes. Further particulars may be obtained from The British Council, 65, Davies Street, London, W.1.

Nickel Disposals

THE Board of Trade announce that they have made an agreement with the Mond Nickel Co., Ltd., under which the latter will offer for sale, as Agents of the Board, 1,600 tons of nickel pellets from the strategic reserves held by the Board. Sales will be made for consumption in the United Kingdom at Mond Nickel's normal selling

price and will, as far as possible, be spread over the period September, 1957, to June, 1958, inclusive. The Mond Nickel Co., Ltd., will offer 500 tons for distribution in the near future.

Stockpile Copper Disposal

In continuation of the policy announced in the 1956 Defence White Paper (Cmd. 9691 paragraph 125) of running down the strategic holdings of industrial raw materials, the Board of Trade are to dispose of a further 27,000 tons of copper. No detailed plan as to method and rate of disposal can be announced until discussions have been held with Commonwealth producers and other trade representatives. But the monthly rate of disposals is in any event unlikely to exceed 2,700 tons. No copper will be offered for sale before October 1957.

Disposal of Government Zinc Stocks

THE Board of Trade announced on December 7th, 1956, that they were about to make arrangements for reducing their stocks of zinc. They have decided to sell about 27,000 tons of zinc in a period of not less than nine months beginning September, 1957. The first sales will be of about 9,000 tons for delivery and pricing over the three months September to November.

The disposal of the remaining 18,000 tons in two or more subsequent three-monthly periods will be the subject of further announcements from time to time. Of the 27,000 tons, about 9,500 tons will be offered for sale by open competitive tender. The tender for the three months September to November, will be for 3,200 tons. The remaining 17,500 tons will be offered to the original suppliers or their agents.

Import Duty on Steel Plates

UNDER the Import Duties (Exemptions) (No. 4) and (No. 6) Orders, 1957, the import duties on a wide range of iron and steel products, including almost all plates, are suspended until March 18th, 1958. After consultation with the Iron and Steel Board about the supply position, Her Majesty's Government have decided to prolong until September 18th, 1958, the suspension of import duty on such plates. A new Order, the Import Duties (Exemptions) (No. 10) Order, 1957, (S.I. No. 1388), has been made, and will come into operation on March 19th, 1958. Copies of the Order may be obtained from Her Majesty's Stationery Office or from any bookseller, price 3d. (by post, 5d.). The question of further suspension of duty on other iron and steel products after March 18th, 1958, is being examined. An announcement in respect of the duties on these other products will be made in due course.

B.O. Fellowship Awards

BRITISH OXYGEN announce the award of three Fellowships for postgraduate research. The awards have been made to MR. J. W. ARNOLD, of London University, for research in the Department of Chemical Engineering, Imperial College; MR. R. K. MACCRONE, of the University of Witwatersrand, Johannesburg, for research in the Clarendon Laboratory, Oxford; and MR. J. B. THOMPSON, of London University, for research in the Department of Physics, University College. Renewal of Fellowship for a third year has been granted to MR. R. A. H. POOL, to continue his research in the Inorganic Chemistry Laboratory, University of Oxford.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

Cr-Mo Steel Welding Electrodes

THREE new chromium-molybdenum-bearing electrodes which deposit weld metal of greater creep-resistance and corrosion-resistance than normal mild steel electrodes, are now being manufactured by Quasi-Arc, Ltd. The increased temperatures and pressures now frequently employed in power stations and oil refineries make creep-resistance an increasingly important factor. The new electrodes—known as 1% Chromium, $\frac{1}{2}$ % Molybdenum; 2 $\frac{1}{4}$ % Chromium, 1% Molybdenum; and 4/6% Chromium, $\frac{1}{2}$ % Molybdenum—have been specially designed for applications for each type of alloy steel, and the weld metal compositions have been carefully balanced to provide satisfactory creep-resistance.

Good welding performance in all positions is claimed for the new rods, with a quiet arc action and easy slag control and detachability. Fully extruded, they have coverings of a basic character to give weld metal of notably fine-grain structure and a very low gas content. Sound weld metal to Class 1 radiographic standards can be deposited in all positions, and on general fabrication work it is possible to build up quite heavy cross-sections of weld metal in one run. The electrodes all conform to the test requirements of the A.W.S./A.S.T.M. specification.

To protect them from moisture, the electrodes, which are available in sizes 12 s.w.g. to 6 s.w.g., are packed in cardboard tubes and enclosed in polythene envelopes which are then packed in strong cartons.

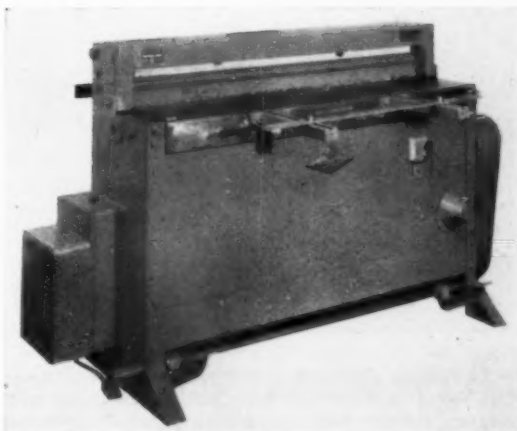
Quasi-Arc, Ltd., Bilston, Staffs.

Power Guillotines

A NEW development in power guillotine design is announced by F. J. Edwards, Ltd., with the introduction of their Besco Production All-Steel Power Guillotines Mark 3. These machines come in three sizes of geared models and one ungeared type. The geared machines, which have a shearing capacity in mild steel of 16 s.w.g., are available in 3 ft., 4 ft. or 6 ft. widths, while the ungeared model is 3 ft. x 18 s.w.g. While the shearing capacities are based upon mild steel sheet they are capable of handling other materials, including non-ferrous metals and, with the top blade ground to a special angle, fibre, plastics, mica and similar substances. Additionally, the machines can be supplied with high speed blades suitable for shearing stainless steel.

One of the most important new advances in the design of this range is the incorporation of a trip latch box as an integral part of the non-repeating, multi-tooth, dog type clutch. This ensures single stroke action even if pressure is maintained on the clutch pedal. However, if continuous stroke action is required it may be obtained simply by disconnecting the latch lever.

The guillotines are of the undercrank type, and are fitted with spring-operated sheet hold-down, which is slotted to give an additional view of the cutting line and automatically grips the material prior to cutting,



ensuring a clean and accurate finish and effectively guarding the operator's hands. Wear on the cutting beam guides is absorbed by adjustable bearing strips of ample proportions, and the top of the cutting beam is covered, giving clean design together with all round protection.

The flywheel, which is fitted with a gun-metal bush to ensure free running, is mounted on the main shaft on the ungeared machine and the driving shaft on the geared models. On the former, the guillotine operates at 120 strokes per minute while on the latter at 50 strokes per minute. A spring-loaded brake, self-compensating for wear, is incorporated to damp the speed of the main shaft before the commencement and upon the completion of its cutting operation.

Motor speeds are 1,000 r.p.m. for the ungeared model and 1,500 r.p.m. for the three geared models. All the guillotines are fitted for repetition work with easily adjusted, standard back, front and side gauges which enable parallel, square and angular cutting to be achieved. In addition, for the convenience of the operator, concealed strip lighting may be fitted to the machines to give a sharp, clear view of the cutting line.

F. J. Edwards, Ltd., 359-361, Euston Road, London, N.W.1.

Degasser for Aluminium Alloys

As a result of extensive research by Foundry Services, Ltd., a new degassing tablet—Foseco Degaser 400—has been developed which, it is claimed, virtually eliminates inclusions and pinhole porosity due to absorbed gases. Covered by Provisional Patent No. 431/57, the new degasser has been under test in several large production foundries over the past few months.

The degassing reaction is controlled so that a smaller bubble size is formed, and this permits greater dispersion, which frees the melt of harmful gases that ultimately lead to porous castings. Tests have shown that Degaser 400 can produce aluminium melts so low in hydrogen



that pinhole porosity due to absorbed gases is eliminated in the heaviest sections. Furthermore, because of the slower and steadier reaction, furring is greatly reduced.

The tablet has a hole in the middle and is threaded on to a hooked plunger rather like an inverted walking stick. When reaction is complete, the residue is removed in one piece, thus eliminating the risk of inclusions. At present Degaser 400 is not recommended for use on LM10 or other alloys where sodium is an undesirable impurity. Nor is it intended for use as a grain refiner, although there is no danger of it in any way coarsening the grain size.

Foundry Services, Ltd., Long Acre, Neshells, Birmingham, 7.

Rust Proofing

THE principle of cathodic protection is applied in a range of rust-proofing materials being produced by Southern Metalife, Ltd. They consist of a finely divided metal, which is anodic to iron and steel, suspended in special plastic media; they can, therefore, be applied by brushing. Metalife PFU is designed for general use where the coating is not subject to severe abrasion, or in contact with strong solvents or chemicals; it is temperature resistant to 212° F. Metalife Wet is suitable for iron and steel surfaces which are often wet, such as piers, ships, exposed structural steel, etc.; this grade is also temperature resistant up to 212° F. For use where abrasion is severe, or where strong solvents or chemicals come into contact with the coating, there is Metalife Heavy Duty—temperature resistant up to 300° F. Where strong acids or alkalis come into contact with the coating, the Heavy Duty grade may be sealed with Metakote Sealer.

The most recent grade (Metalife ATR) has been developed for rust proofing steel surfaces subjected to high temperatures, such as are encountered in steel chimneys. Most paints soften at temperatures above 200° F., but special heat-resisting paints can give good protection at temperatures above 700° F. The latter, however, depend on the high temperature to stove, cure or alloy the aluminium coating to the steel, and they are not effective at temperatures below 550° C. Metalife

ATR is applied cold by brush or spray gun, and dries to leave an anodic coating which withstands all temperatures up to 550° F.

Southern Metalife, Ltd., James Street, Harrogate, Yorks.

G.K.N. Spark Machine

ELECTRIC spark erosion enables work which is often beyond the capabilities of normal machining methods to be carried out with comparative ease, and it is now possible to produce the most intricate shapes in "difficult" materials with speed and accuracy. The G.K.N. Spark Machine has been designed to meet the requirements of a wide range of industries, and combines a high cutting rate with good surface finish, low electrode wear and simplicity of operation. It comprises three main units—the working head, the electrical supply, and the dielectric fluid system.

The electrical circuit is of the basic relaxation type, but incorporates special devices to reduce the tendency to arc which is always present with the simple relaxation circuit. Because of the greater stability, high cutting rates can be achieved for a given finish. The standard machine is suitable for operating on a 400-440 volt, 3-phase supply.

The removable working head has 3-point support in the substantial dielectric fluid tank, which makes for greater accuracy in the finished work. The servo drive is from a D.C. motor, through a friction reduction unit, to an arbor carrying a vee-block for holding the electrode. The object of the friction drive is to eliminate backlash in the system, which would cause instability of the servo system. The work table is of ample proportions for holding workpieces and work holding fixtures.

The electrodes are normally of copper, which has a low wear ratio, or, in special circumstances, of brass or other materials. The accuracy of the work produced depends on the shape and accuracy of the electrode, but in general a tolerance of 0.002 in. is easily held, and if required this can be reduced to 0.001 in. or even 0.0005 in. A striking feature of the machine is the ease whereby a succession of electrodes can be quickly and accurately set on a given workpiece. A vibrator unit is arranged so that a small oscillation can be superimposed on the servo drive. It has been found beneficial to use the vibrator when commencing a cut or in difficult



conditions—such as deep holes—but the vibrator is not normally used when cutting.

The table of the machine is connected to the positive lead of the circuit and the arbor to the negative side. The negative side is earthed so that all the head except the table is at zero potential. The table itself is insulated from the base of the head and is immersed in a dielectric fluid during operation. The dielectric system consists essentially of a storage tank, pump, work tank, by-pass filter and means for controlling the flow of liquid through the gap between the electrode and the workpiece, if such a flow is desired for any particular job.

Rudkin & Riley, Ltd., Cyprus Road, Aylestone, Leicester.

Platinum Resistance Thermometer

In view of increasing requirements for the control of furnaces at high temperatures, and particularly for creep testing furnaces, C.N.S. Instruments, Ltd., have recently introduced a platinum resistance thermometer giving repeatable and stable performance at temperatures up to 1,200° C. Used in conjunction with a C.N.S. proportional temperature controller, the 5-6 ohm. resistance thermometer will cover a temperature range of 100-1,200° C.

The thermometer is housed in a recrystallised alumina sheath impervious to all industrial furnace gases including hydrogen. The standard sheath is 0.3 in. O.D. x 6 in. or 10 in. in length. The standard sensitive elements, which have a cold resistance of 5-6 ohms. or 9-10 ohms., are non-inductively wound on to a former which is separately supported from the sheath. There are no welds, as the platinum element wire is continuous throughout. The dimensions of the components are such that the maximum response to temperature change is ensured whilst affording protection to the sensitive element against mechanical and chemical damage. The sensitive element remains undisturbed and therefore provides stable operation at temperatures high enough to cause creep in the recrystallised alumina sheath.

High stability has been achieved by a novel form of construction, enabling a control accuracy of $\pm 1^\circ \text{C.}$ to be achieved at 1,200° C. Long-term drift from the controlled temperature at this high level is within the accuracy of measurement of platinum/platinum-rhodium thermocouples.

C.N.S. Instruments, Ltd., 61 Holmes Road, London, N.W.5.

Metal Sprayers' Helmet

A COMPLETELY new type of protective helmet for use in the metal spraying industry has recently been introduced by Metallizing Equipment Co., Ltd. The preliminary function of the helmet is to provide fresh, clean air to an operator otherwise exposed to the hazard of dust and fumes present when spraying toxic materials, and at the same time afford the maximum comfort and cleanliness to the wearer. Air to the mask is controlled by a small valve incorporating a safety by-pass, and fed through an easily replaceable activated carbon filter element to remove oil fumes from the compressed air. Large bore, lightweight hose is fitted, and connects to a distribution box developed to silence the internal noise to a minimum. A quick release connection in the main air supply, combined with a spring-loaded flap valve, enables the wearer to disconnect himself from his air supply line



during "down periods" and breathe freely without removing the helmet. Such operations as replacing oxygen or acetylene cylinders, moving the workpiece, etc., can be readily carried out with the minimum of effort.

An important feature of the new type mask is the freedom of vision. Made from lightweight, transparent material, and making no contact with the head, the main hood dispels any feeling of being "shut in." Spectacles may be worn with complete freedom. A clear, replaceable front visor is incorporated into the helmet which can be readily renewed after prolonged service. Internal, flush fitting demisting baffles fan the incoming air to prevent any steaming up of the internal surfaces and reduce any tendency towards internal draught. The unit is supplied complete with all fittings and connections.

Metallizing Equipment Co., Ltd., Chobham, Woking, Surrey.

Burner Watcher

A NEW burner control box—the Spediflam II—developed by Teddington Industrial Equipment, Ltd., incorporates a number of interesting features, making it one of the most advanced form of protection available today for oil-burning installations. Among its many new safety factors is a re-set button which is positively isolated from the control circuit until the full purge period has elapsed, thus ensuring constant purging time under all conditions. Other features of the thermal types include positive timeset ignition period after flame is established; specially designed constant torque, magnetic clutch for positive, rapid shut down on flame failure with minimum temperature drop; ignition transformer and burner pump motor energised simultaneously by one master relay with self-cleaning contacts. Other special features include chassis type construction, concealed wiring, built in radiation shield, special easy wire terminals and the timers shielded in transparent Perspex. The thermal pattern Spediflam II is available either as a combined model for flue mounting, or as a separate box and separate flue stat where chassis or wall mounting is preferred.

In addition to the thermal models, two electronic models are available with a new photo-electric detector which has a wide sensitivity adjustment. It will operate on light levels down to 40 lux, and is particularly suitable where flame flicker is a problem. One model has a purge timer where a full purge period is required. The other

model has no purge timer, but a special feature of its design is that it provides a purge period after lock-out and, therefore, still complies with S.799.

Teddington Industrial Equipment, Ltd., Sunbury-on-Thames, Middlesex.

New Document Copying System

THE Kodak Verifax copier, based on an entirely new principle, has been designed for the accurate copying of letters, reports, schedules, diagrams, etc., up to $8\frac{1}{2} \times 14$ in., in the shortest possible time. It will produce a copy in 50 seconds—three in less than a minute.



The Verifax copier is self-contained, and takes up little more room on an office desk than an ordinary typewriter, yet it can complete the equivalent of one day's copy-typing in less than an hour (e.g., up to six copies each of forty or more documents). The paper is stored and kept ready for use inside the copier, and a built-in trimmer is located on top of the unit for trimming copies when necessary.

The equipment is extremely simple and can be operated by any member of the office staff, as it requires no photographic or technical knowledge whatever. It frees typists and other members of the staff for more important duties and, since copies are photographically accurate, eliminates copy-reading and checking. The copier can be used in normal office lighting.

Kodak, Ltd., Kingsway, London, W.C.2.

Arc Welding Electrodes

THE English Electric Company has now introduced a new range of arc-welding electrodes particularly suitable for vertical and overhead welding, in addition to welding in the flat and horizontal positions. These electrodes, known as Vohees, have been developed primarily to meet the needs of the shipbuilding industry, and also users who prefer to have one electrode for all welding positions.

Vohees are manufactured in sizes from 12 s.w.g. to $\frac{1}{4}$ in. diameter. Electrodes from 12 s.w.g. to 6 s.w.g., inclusive, are suitable for overhead work, from 12 s.w.g. to 4 s.w.g. for vertical work, and the complete range for all horizontal-vertical welding. These electrodes are of the medium penetration type, suitable for welding with poor fit-ups. They give a stable arc, can be used with low current and produce little spatter. No special weld-

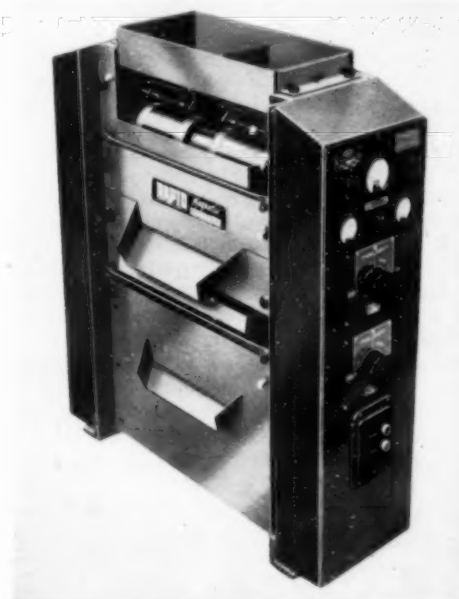
ing procedure is required. Slag is of the fluid, quick-freezing type, being easily removed and often self-detaching.

Vohees are designed to operate with A.C. or D.C. The B.S.1719 classification is E317, and the American classification is E7013. They also comply with the requirements of B.S.782, B.S.639 and B.S.2549. Lloyd's Register of Shipping, the Ministry of Transport and the Admiralty have approved Vohees electrodes for the welding of mild, D, DW and S quality steels.

The English Electric Co., Ltd., Marconi House, Strand, London, W.C.2.

Magnetic Separator

RAPID MAGNETIC MACHINES, LTD., have introduced a new high intensity, induced roll separator, which provides the necessary magnetic field for purification of free flowing granular materials. A considerable reduction in overall size, and wattage below hitherto applicable machines has been achieved. The basic unit has a 5 in. diameter roll, with two parallel 5 in. feed widths. Several such units may be fitted together to provide a separator with any number of rolls for difficult separations, or where selective separation of different materials is required.



The equipment is particularly applicable for the purification of such items as silica sand, abrasive grain, corundum, graphite, kyanite and slag. The capacity is dependent upon the material size and magnetic susceptibility, but typical figures are $1\frac{1}{2}$ tons per hour for the purification of silica sands.

In addition to its rugged construction, sealed bearings are used throughout, and for ease of maintenance, every part of the separator is either removable, or readily accessible. Each magnet coil is rheostatically controlled, thus allowing variation of energy at each roll.

Rapid Magnetic Machines, Ltd., Lombard Street, Birmingham, 12.

CURRENT LITERATURE

Book Notices

RECOMMENDATIONS FOR THE TESTING OF ALUMINIUM FUSION WELDS AND WELDERS

Addendum to Information Bulletin No. 19. 16 pp., 8 sketches. The Aluminium Development Association, 33, Grosvenor Street, London, W.1.

The considerable advances made in the development of welding techniques for aluminium, especially over the last few years, emphasise the need for guidance in the matter of testing. Accordingly, the appropriate technical committee of the Aluminium Development Association has prepared a document intended to meet the needs of authorities who have cause to test welds and approve welders engaged on the fabrication of aluminium.

The first section of the booklet deals with current testing methods, as divided between non-destructive and destructive tests, and continues with notes on the applications of these methods to butt welds and fillet welds in aluminium. Illustrations are given of appropriate test specimens. The second section describes the making of test welds, and it is noted that the welder should be tested, as far as possible, on the gauges and compositions of material with which he will be chiefly concerned. Finally, there is a list of defects occurring in welds made by the principal methods, and here, considerable care has been taken to distinguish, as appropriate, between defects due to negligence or inefficiency of the welder, and defects inherent to the process itself.

The present notes will, in due course, be incorporated into A.D.A. Information Bulletin No. 19 "The Arc Welding of Aluminium." Meanwhile, copies of the Addendum are available on request to the Association.

UNDERGROUND CORROSION

By Melvin Romanoff. National Bureau of Standards Circular 579, issued April, 1957. 227 pages, 103 illustrations. \$3. (Order from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Foreign remittances must be in U.S. exchange and should include an additional 75c. to cover postage.)

THE corrosion of metallic structures buried in the ground or in contact with soil has long been a serious engineering and economic problem. There are in the United States almost 1 million miles of gas, water, and oil pipelines, 425,000 miles of railroad tracks, 170,000 miles of buried communications, signal, and power cable systems, as well as unknown numbers of other structures, such as tanks, pilings and burial vaults. The annual loss to the American pipeline industry alone, from actual destruction by corrosion and the cost of preventing corrosion, is estimated to be in the order of 600 million dollars. In addition, a higher and undeterminable cost results indirectly from corrosion through the loss of products, shutdown of services, and loss of life and property by fire and explosion.

This circular which supersedes NBS Circular 450, issued in 1945, is a final report on the studies of under-corrosion conducted by the Bureau over a period of 45 years. Up to 1922, the studies were confined to corrosion due to stray-current electrolysis and its

mitigation. After it became apparent that serious corrosion occurred in soils under conditions that precluded stray-currents as an explanation, a field burial programme was initiated in order to obtain information pertaining to the effect of soil properties on the corrosion of metals. Approximately 37,000 specimens, representing 333 varieties of ferrous, non-ferrous, and protective coating materials, were exposed in 128 test locations throughout the United States. During this time the electrical and electrochemical aspects of underground corrosion, including cathodic protection, have been continuously studied in the laboratory. Results from both field and laboratory investigations are presented in the circular. Also included are many references to industrial investigations and field experiences related to the Bureau's underground corrosion investigations.

RAILWAYS AND STEEL

Prepared by the Steel, Engineering and Housing Section of the Secretariat of the U.N. Economic Commission for Europe. U.N. Publication Sales No. 1957.II.E.3. \$0.60; 4s. 6d. sterling; 2.50 Swiss francs.

THIS 65-page report is the third of a series devoted to the economic aspects of the production and consumption of important steel products, the two already published being "The European Steel Industry and the Wide-strip Mill" and "The European Pipe and Tube Industry."

Demand for rails and steel for building railway rolling stock has always been unstable, and its evolution has followed a pattern substantially different from that of other steel products. The railway administrations of different countries have not had the same degree of fortune in meeting competition from other means of transport; some of them have drawn up important modernization schemes; and many countries which were traditionally importers of railway materials have now engaged in their production. A better knowledge of the prospects of railways and of their steel requirements is therefore of considerable interest to the European steel industry.

Written with the assistance of most of the European railway administrations, the International Railway Union (IUC), and the International Association of Rolling Stock Builders (AICMR), the report makes a thorough analysis of the evolution of production and requirements of steel for the railways, and studies the consequences for steel requirements of such problems as electrification, greater traffic speed, shorter turn-round time, etc. It also studies the development of railways and the evolution of production of railway materials outside Europe and draws conclusions as to future export prospects for rails and rolling stock.

The scope of this report is comprehensive and thorough as can be seen from the following chapter headings: Production of Railway Material and Rolling Stock; Some Factors affecting the Demand for Steel by the Railways; Official Programmes in the Railway Field; Overseas Export Prospects; and Some General Conclusions. In a number of appendices, extensive additional information is given on the production of permanent-way material, tyres, wheels and axles and rolling stock; the age structure of Europe's railway-

vehicle park; the number of railway vehicles placed in service in recent years; the length of railway networks and the importance of the vehicle parks of practically all the countries in the world; and underground railways. A list of the international non-governmental railway organizations is also given, explaining their aims and the nature of their work, and describing briefly their spheres of interest.

Trade Publications

TUBE INVESTMENTS is now making available to interested companies pilot plant quantities for testing of an irradiated polyethylene tape or film which has been proved to have a number of important industrial applications. The room temperature properties are improved and its susceptibility to environmental stress cracking is largely eliminated. It is at elevated temperatures that the improvement is most marked. The irradiated material can be used at temperatures far in excess of those at which the conventional low-density or the new high-density varieties of polyethylene melt to a mechanically useless fluid. The properties of this tape and a list of possible uses are given in a new leaflet entitled "Irradiated Polythene Tape."

WITH the title of Savings and Investment, the United Steel Co., Ltd., have recently issued an employee publication describing in simple terms the principles of shareholding, and some methods of investment. It points out that, where long-term saving is concerned, there are many advantages in owning shares; and the guide aims at showing both sides of the question. It also emphasises that industry needs the savings of its workpeople to finance its future, but it is made quite clear in the foreword that the Company is not advising employees to do anything.

IN 1956 the Council of the British Iron and Steel Research Association decided to establish a Computer Applications' Section within the Association's Operational Research Department, and to buy a computer, which is to be delivered this year. The Council also commissioned a booklet to explain as simply as possible the general way in which such machines work, and why they are likely to prove important to the industry. In a foreword to the booklet, which bears the title "Computers and Steel," Capt. H. Leighton Davies, C.B.E. (Chairman of B.I.S.R.A. Council) emphasises that the operation of the machines will not become effective in industry unless managements are aware of their potentialities and are prepared to consider how they might be used.

THE Iron Ore Company of Canada announces publication of two booklets providing information on employment opportunities in the company's New Quebec-Labrador operations. Available on request are "Welcome," newly published employee induction booklet, and "There's a Future in Iron Ore," an outline of opportunities for university graduates, now appearing in its second edition. In addition to a description of the Iron Ore Company operations, the latter booklet focuses attention on the opportunities in the company for professional people, including mining engineers, geologists, metallurgical engineers, civil engineers, electrical engineers, electronic specialists, as well as arts and commerce graduates. Many opportunities also exist in the Iron Ore Company affiliate, the Quebec North Shore

and Labrador Railway, which transports the ore 350 miles from the Shefferville mines to Sept-Îles on the St. Lawrence River. Both booklets and further details may be obtained by writing to the Personnel Department, Iron Ore Company of Canada, Sept-Îles, P.Q., Canada.

It is more than twenty-five years since Imperial Chemical Industries, Ltd., introduced the trichloroethylene metal degreasing process, which can be adapted to almost any kind of work, provided the contamination is soluble in trichloroethylene or is held to the work by trichloroethylene-soluble materials. Since its introduction, it has found widespread application in both standard plants and plants specially designed for a particular operation. The plants can cater for cleaning by immersion in vapour, immersion in liquor, or combinations of the two. A new brochure issued by Imperial Chemical Industries, Ltd., deals with the process itself, equipment for its operation, methods of handling, and safety measures.

WITH the title of "Clean Air Saves Money," Radiovisor Parent, Ltd., have recently issued a folder dealing with two smoke density measuring devices. The RV.2 measures smoke density in terms of light obscuration and provides an indication on a 6-in. meter; an alarm circuit is also incorporated. The SA.56 provides an alarm only; it does not indicate smoke density on a meter. Both types of equipment are based on photo-electric measurement of light, and a recorder can be fitted with either unit.

THE August, 1957, issue of *Close-Up*, the house magazine of Armstrong-Whitworth (Metal Industries) Ltd., and Jarrow Metal Industries, Ltd., features an article on refined pig iron, which tells the story behind A.W. Refined Pig Iron, whose use has been an important factor in the development of high strength grey iron castings for a number of prominent engineering firms, both here and abroad. The most recently introduced grades have been developed for the manufacture of spheroidal graphite iron.

Books Received

"Pneumoconiosis." Industrial Diseases of the Lung caused by Dust. By Dr. P. F. Holt. 268 pp. inc. author and subject indexes. London, 1957. Edward Arnold (Publishers), Ltd. 50s. net.

"Acieristes et Fondeurs." Le Four Electrique Basique. By H. Bourdon. Preface by A. Michel. 114 pp. Paris, 1957. Dunod. 880F.

Proceedings of the Seventh Meeting of the International Committee of Electrochemical Thermodynamics and Kinetics. 409 pp. London, 1957. Butterworths Scientific Publications. 84s. By post 1s. 6d. extra.

"La Pratique des Traitements Thermiques des Métaux Industriels." By G. de Smet. Preface by G. Bouteiller. 5th Edition. 466 pp. Paris, 1957. Dunod. 3,300F.

"Metallurgy." By C. G. Johnson and W. R. Weeks. 4th Edition. 454 pp. inc. glossary and index. London, 1957. The Technical Press, Ltd. 46s. net.

"The Solidification of Castings." By R. W. Ruddle. Second Edition. Institute of Metals Monograph and Report Series No. 7. 406 pp. inc. name and subject indexes and numerous illustrations. London, 1957. The Institute of Metals. 42s. (\$6.50).

LABORATORY METHODS

MECHANICAL • CHEMICAL • PHYSICAL • METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

SEPTEMBER, 1957.

Vol. LVI, No. 335

An Apparatus for Measurement of the Occlusion of Hydrogen by Metals*

By M. Kotyk, M.Sc.,† J. K. Magor, M.Sc.,‡ and H. M. Davis, M.Sc., Ph.D.§

An apparatus is described in which a metallic specimen immersed in hydrogen of known pressure and volume at or near room temperature is heated at a succession of higher temperatures until equilibrium between gas and metal is established. Comparison with data obtained in similar experiments using a glass dummy specimen enables the amount of hydrogen occluded at any temperature to be determined.

CONSIDERABLE research has been devoted to the study of occlusion of hydrogen by iron and its alloys.^{1, 2, 3} "Occlusion" is here defined as a shutting-in, or containment, without specification of the nature of residence of the contained substance. The effects of occluded hydrogen upon the physical and mechanical properties of metals are widely recognized, but a detailed quantitative knowledge of occlusion and an understanding of its mechanisms will yet require much precise and reliable data which can be acquired only through the use of adequate apparatus and techniques.⁴ The apparatus described herein may be of use to those seeking to increase the store of valuable data.

In the study of hydrogen-metal systems, the most widely used methods of charging hydrogen into the metal have been (1) acid immersion, (2) cathodic discharge, and (3) gas immersion. It is convenient to refer to hydrogen provided by these methods as (1) acid hydrogen, (2) cathodic hydrogen, and (3) thermal hydrogen (i.e., provided through thermal dissociation of molecular hydrogen). The apparatus described below is for measurement of the occlusion of thermal hydrogen provided by an atmosphere of hydrogen gas.

Apparatus

Any apparatus of this sort must inevitably contain many of the features of that originally designed by Sieverts.⁵ The principle of the present apparatus is that the metallic specimen, immersed in hydrogen of known pressure and volume at or near room temperature, is heated at a succession of higher temperatures until equilibrium between gas and metal is established at each temperature, whereupon a pressure-volume product for that temperature is obtained. A reference series of similar pressure-volume data is prepared in identical manner in a blank experiment in which the metallic

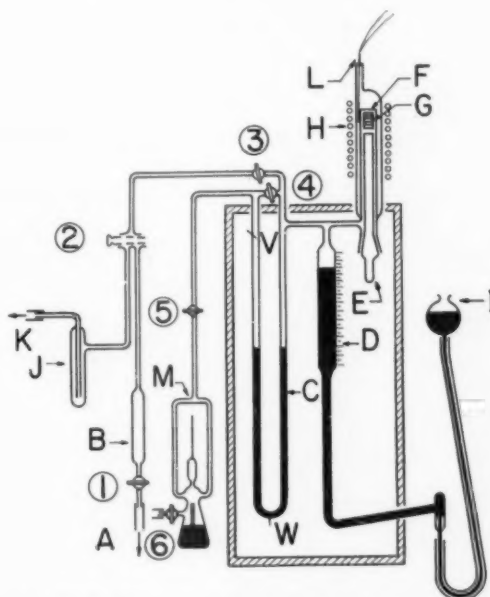


Fig. 1.—Occlusion retort, with exhausting, filling and measuring systems.

specimen is replaced by a dummy of glass (of equivalent volume) which occludes no hydrogen. The difference between an experimental volume and the reference volume at any temperature gives the quantity of hydrogen occluded by the metal at that temperature.

The retort, *F*, of Fig. 1 is adapted to a metal specimen in sheet, plate, or massive form. If massive, the metal is turned into the form of an annular cylinder. If in the form of sheet or plate, the metal is cut into a number of washers which, when stacked, will make a cylinder of the same size. From the measured density of the metal, a specimen of known volume, equal to that of the dummy used in the blank experiment, is prepared by weight. The cleaned specimen, *G*, is laid on the carrier, *E*, and the two are slipped into the retort, *F*. The tapered joint

* Contribution No. 56-52 from the College of Mineral Industries of The Pennsylvania State University.

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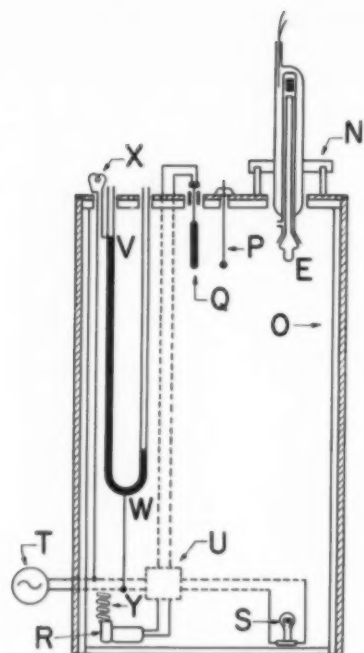


Fig. 2.—Constant-temperature cabinet and control system.

is then sealed with a wax melting at approximately 80° C. ("Pyseal"; Fisher Scientific Company). A central glass pin protruding from a well in the carrier (not shown in the diagrams) keeps the specimen in place during its insertion. Carrier and specimen together fill the retort, so that the small volume change due to the occlusion of hydrogen by the metal at any temperature will be a significant fraction of the volume change due to thermal expansion of the gas.⁶ With the sample in place and the retort sealed, the system is evacuated and proven tight. Dried, oxygen-free hydrogen is then admitted, and the specimen is heated for reduction of any superficial oxide. It is afterwards outgassed by a routine appropriate to the metal. At the conclusion of the outgassing period, stopcock 4 is closed so that the manometer, *C*, becomes functional. Beside its use in measurement of the residual pressure in the entire evacuated system, the McLeod gauge, *M*, is periodically used for checking the pressure in the evacuated left arm of the manometer after stopcock 4 has been closed and while the prolonged exposure of the specimen to hydrogen is in progress.

The electrolytic hydrogen is admitted through a catalyst ("Deoxo" unit; Baker and Company, Inc.) to the drying column, *B*, containing phosphorus pentoxide, whence the "oxygen-free," dried gas is slowly admitted to the evacuated retort and the metal specimen. The pressure of the hydrogen about the specimen is precisely adjusted by movement of the mercury levelling bulb, *I*. The working pressure of 710 mm. of mercury (selected to be below local atmospheric pressure for safety of the tapered joint) is indicated by the glowing of lamp *X* of Fig. 2, which is connected to the 115-volt alternating-current source *T*, through the tungsten contacts, *V* and *W*, in the manometer.

The lightweight furnace, *H*, consists of an asbestos-insulated winding of 0.040-in. Kanthal-A resistance wire

(Kanthal Corp.) over a tube made from 0.010-in. sheet nickel. At any temperature, *t*, up to 550° C., the temperature within every part of the 1½-in. sample zone lies within the range $t \pm 1^\circ \text{C}$. The temperatures are indicated by a Chromel-Alumel thermocouple, *L*, whose test junction is located opposite the midpoint of the sample zone. An electronic indicator-controller is used for controlling the temperature of furnace and sample.

Fluctuations in the measured gas-volume resulting from changes in room temperature are minimised by enclosure of virtually all of the volumetric system within an insulated plywood cabinet, wherein a constant air temperature of $34.2 \pm 0.2^\circ \text{C}$. is maintained. A schematic diagram of the cabinet and its control system is shown in Fig. 2. That portion of the retort which is not covered by the furnace is housed within an insulated extension of the cabinet, *N*. By this arrangement, the wax seal of the carrier-retort tapered joint is protected against damage by heat from the furnace.

The mercury-filled thermoregulator, *Q*, working through a 115-volt, 1-milliampere relay, *U*, alternatively activates the blower, *R*, or the lamp, *S*, to lower or raise the air-bath temperature. For achievement of maximum temperature stability in the cabinet, it is generally necessary to circulate cool water through the copper coil, *Y*, over which air from blower *R* passes. A circuit diagram for the constant-temperature cabinet is shown in Fig. 3.

Operation

After the sample is in place and the retort is sealed, the levelling bulb, *I*, is lowered to a position such that, when the system is evacuated, the mercury level at barometric height will fall within the scale of the burette, *D*. Stopcocks 2, 3, 4 and 5 are opened to the water-freeze-out trap, *J*, and the vacuum-pump manifold, *K*. After the system has been thoroughly evacuated, stopcocks 3 and 5 are closed. By orderly manipulation of stopcocks 1, 2 and 3, approximately ½ atmosphere of hydrogen is admitted to the retort. Levelling bulb *I* is raised until the pressure of the contained hydrogen is ca. 600 mm. Final deoxidation of the sample is now accomplished by exposure to hydrogen at a suitable elevated temperature. The levelling bulb is then lowered to its former level, after which the system is evacuated. The sample is outgassed for a half-hour at the elevated temperature,

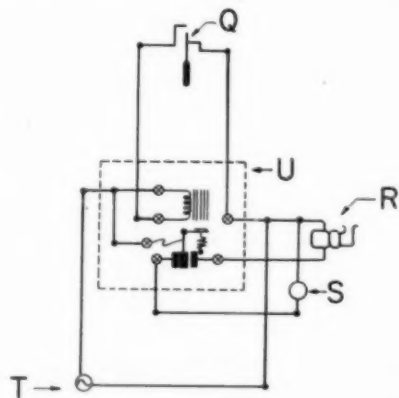


Fig. 3.—Circuit diagram for the constant-temperature cabinet.

TABLE I.—REPRODUCIBILITY OF REFERENCE DATA FOR THERMAL EXPANSION ALONE.

Blank Temperature °C.	Volume Change (cc)	
	Blank Run No. 1	Blank Run No. 2
40	0-00	0-00
100	2-10	1-96
150	3-40	3-23
200	4-41	—
250	5-24	5-19
300	6-00	—
350	6-00	6-59
400	7-15	7-15
500	8-12	8-06
550	8-46	8-47

and outgassing is continued during a rapid cooling to room temperature. For some materials, repeated deoxidation and outgassing treatments may be necessary. After the sample has been thoroughly outgassed, and the system is again isolated from the pump, stopcock 4 is closed so that the left arm of the manometer may remain evacuated. Furnace *H* is then employed to warm the sample to some starting temperature, e.g., 40° C. Stopcock 3 is slowly opened to admit approximately $\frac{1}{2}$ atmosphere of hydrogen to the retort. The mercury levelling bulb is quickly raised to compress the contained hydrogen to 710 mm. pressure, indicated by the flickering of lamp *X*. The mercury level in burette *D* is recorded as quickly as possible after the admission of hydrogen to the sample retort, lest the basal volume be established after undetected occlusion has occurred. The equilibrium

volume is then determined at as many higher temperatures as are judged necessary. Equilibrium at a given temperature is considered to be attained when the rate of change in volume is equal to the measured leak rate of the system at that temperature. With a retort of Pyrex-brand glass, measurements may readily be made at 550° C. With a retort of silica glass, the range may be somewhat extended, but the high permeability of this glass to hydrogen makes reliable measurement difficult above 750° C. When the final measurement is made and the retort has been cooled to room temperature, it is necessary to isolate the McLeod gauge and to join the two arms of the manometer before the retort is opened to the atmosphere.

The reproducibility attained with an apparatus of the above design employing a sample having a volume of 13-30 cc. is revealed in Table I, where reference data from two blanks are tabulated.

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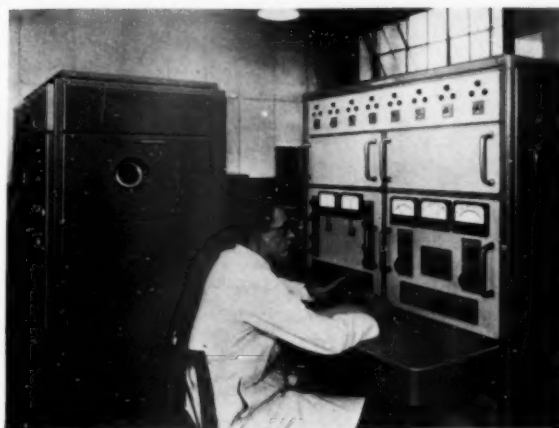
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The Analysis of Inorganic Solids by the Mass Spectrometer

UNTIL recent years the main applications of the mass spectrometer have been to the isotopic assay of gases and liquids, and to the chemical analysis of volatile inorganic and organic compounds. This work can be carried out over a large mass range, and organic compounds containing up to forty or more carbon atoms can be investigated. However, while this remains a very important field of application, one of the most striking developments in recent years has been in the analysis of inorganic solids. Two special types of mass spectrometer have been designed by Metropolitan-Vickers for this purpose—the MS5 for the determination of isotope ratio using the surface ionization technique, and the MS7 for the analysis of impurities using the spark ionization technique.

Surface Ionization Technique

The basic problem in solid analysis is to produce positive ions that are truly representative of the sample composition. A number of methods have been tried, one of the more successful being the technique of surface ionization. There are several slightly different versions of this method, but in its simplest form the solid sample, in the form of a salt such as the nitrate or sulphate, is painted directly on to the surface of a tungsten filament. When the filament is heated, positive ions are emitted directly from the surface and are identified and measured using conventional mass spectrometric techniques. The surface ionization technique is not particularly suitable for the general analysis of solids, because different elements have widely different sensitivities, but it is ideal for the measurement of isotope ratios of solids. The type MS5 mass spectrometer has been specifically designed for use on this problem.



Type MS7 mass spectrometer installed at the B.T.H. Research Laboratories.

This instrument is a 12 in. radius 90° sector single-focussing mass spectrometer for use with either the single or triple filament surface ionization technique. Two particular features of the instrument are (i) a sliding-bar vacuum lock system, which enables the sample to be introduced into the instrument in less than a minute; and (ii) an ion collector system, which provides for the simultaneous availability of a normal collector (noise level approx. 3×10^{-15} A), and an electron multiplier (equivalent noise level less than 10^{-18} A.). A resolving power of at least 300 can be obtained.

Nearly 75% of all the elements respond to the surface ionization technique, including most metallic elements. The normal size of sample is a few micrograms, but with certain elements 10^{-11} grams will enable approximate determinations of isotope ratio to be carried out. The time required for an analysis varies from 10 minutes to 1 hour, depending on the element and the sample size available.

Spark Ionization Technique

A method of ionization of solids employing the vacuum spark is approximately equally sensitive for all the elements. However, the use of this technique requires a double focussing instrument because of the large energy spread in the ion beam produced.

The type MS7 mass spectrometer is designed for the general analysis of solids by the spark ionization technique. It is a double focusing instrument of the Mattauch type, in which positive ions, representative of the sample composition, are produced when a high-voltage spark occurs between two electrodes formed of the sample material and placed close together in vacuum. After passing first through an electrostatic analyser and then

through a magnetic analyser, the ions come to focus according to their mass as a series of lines on a photographic plate.

One of the most promising applications of the instrument is to the analysis of impurities in solids. For this work the photographic plate is used as an integrating device, and a series of exposures of gradually increasing length is taken (a rack mechanism allows up to ten exposures to be recorded on the same plate, and the exposure is accurately determined by the total integrated charge falling on the monitor collector). The concentration of the impurity is estimated from the intensity of the lines on the longer exposures, and with this technique concentrations down to the level of 0.1 p.p.m. can be estimated.

The method is particularly useful for giving a general picture of the impurities in a solid. The whole mass range from 7-240, covering all elements, can be recorded in a single exposure of the photographic plate. Compared with emission spectroscopy the spectra are simpler and the elements easier to identify. Moreover, qualitative and semi-quantitative analyses can be carried out without extensive calibration.

Items of Metallurgical Interest at Recent Instrument Exhibitions

The recent Instruments, Electronics and Automation Exhibition at Olympia aroused considerable interest, as might be expected at a time when automatic devices are finding increasing application in industry and commerce. In this series of articles, reference is made to items of metallurgical interest exhibited at Olympia, and at the Physical Society Exhibition which, as usual, provided an opportunity for the display of new commercially available and prototype instruments and laboratory equipment.

Specialised Arc Furnaces

DURING the past few years great interest and effort has been directed to the melting of pure refractory metals and alloys. Due to their very high melting points and their general refractory behaviour, melting and alloying of these materials is difficult to accomplish with conventional techniques. A solution to the problem has been found using a direct arc as the heat source and a water-cooled copper hearth as the crucible material. The arc furnace developed by Edwards High Vacuum, Ltd., utilises this principle in two forms, in one of which the electrode is consumable and in the other it is not.

The latter uses a tungsten electrode held in a water-cooled copper stem which is externally connected to the negative pole of a D.C. generator, the positive pole being connected to a flat bottomed water-cooled copper hearth. Using this arrangement, specimen buttons of high purity may be prepared in a low pressure argon atmosphere, temperatures in the region of $4,000^{\circ}\text{C}$. being attainable. Tungsten and molybdenum buttons may be readily prepared from sintered pieces of the metal, and the technique may also be adapted for making finger type ingots by replacing the usual flat-bottomed hearth with a hearth shaped to permit casting in a horizontal plane.

In the other form a consumable electrode of the metal or alloy to be melted is held on a water-cooled copper

feeding stem, which is externally connected to the negative pole of a D.C. generator. A hearth is formed by a water-cooled copper tube with a positive connection to the generator. This arrangement is suitable for producing ingots up to 5 lb. steel capacity, and with this method melting can be carried out in a continuously evacuated system. In general, the use of this system extends up to temperatures in the region of $2,600^{\circ}\text{C}$., and it is expected that considerable work will be carried out on conventional metals and alloys, as these may also be cast in the arrangement provided. Working temperatures in excess of $2,600^{\circ}\text{C}$. may be obtained by this technique, but a change in generator characteristics and water-cooled devices is necessary. A coil is wound round the outside of the water jacket to cover the length of the mould, so that, on passing a current of about 0.2A. through the coil, a suitable magnetic field is obtained which secures mixing of the metal and stabilisation of the arc.

Thickness Measurement

The Type 1108 Visigauge on the stand of Dawe Instruments, Ltd., measures the thickness of material from one side by determining the fundamental natural frequency of vibration in the thickness direction, the result being indicated directly on a calibrated scale of a 21 in. cathode ray tube.



The Dawe Visigauge.

A crystal transducer is energised by an R.F. oscillator and the ultrasonic vibrations produced are coupled to the material under test by a thin film of oil or grease. These vibrations pass through the material and are reflected from the opposite surface. At certain frequencies the vibrations set up fundamental or harmonic standing waves in the thickness direction, and when this resonance occurs extra power is drawn from the oscillator. The pulse of extra power is amplified and used to produce a vertical trace on the cathode ray tube at a position related to the thickness.

By choice of frequency range and crystal type, the instrument will measure the thickness of most metals and many insulating materials, provided they are good conductors of ultrasonic waves. Specially shaped crystals enable tests to be carried out from cylindrical and spherical surfaces. The equipment can also be used to detect internal defects within materials, such as laminations, inclusions, and lack of bond between materials.

Typical applications for thickness measurements are aircraft propellers, hollow aluminium extrusions, milled and tapered sheets, aluminium and magnesium castings, plate glass, seamless tubes of brass, steel and aluminium, forged and bored tubes, centrifugally cast iron pipes, and lead-covered cables. The provision of facilities for connecting up to 1,000 ft. of cable between the transducer and the equipment makes the Visigauge particularly suitable for large scale surveys, such as on ships and oil refining installations, for example.

Transistor Type Electronic Controller

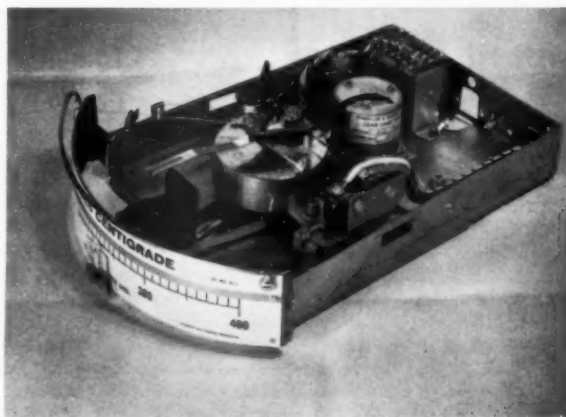
The exhibits of Kelvin & Hughes (Industrial) Ltd., at Olympia included a new transistor-type electronic controller. Employing a sensitive moving coil microammeter in the measuring section and an "indefinite life" photo-transistor in the control section, it can be applied to any process where the variable to be measured and controlled can be converted into millivolt output. The principal application is, however, in conjunction with a thermocouple or resistance thermometer, for measurement and control of temperature.

The offset moving coil has a high torque/weight ratio,

and is magnetically suspended to minimise the effects of shock and maintain accuracy. A patent dual locking and coil shunt arrangement prevents damage to the movement during storage and transit. Automatic compensation is provided for changes in coil resistance with temperature, and in the cold junction temperature.

A red pointer carried on a radial arm indicates control "set" point. The arm also carries a light source having a pre-focus lamp operated at far below full rating, and this is focused on to a photo-transistor by a spherical mirror. A vane attached to the measuring pointer passes freely between mirror and photo-transistor. Below "set" point, the photo-transistor receives full illumination of the light source, energising a relay to operate a switch to the "make" position. When "set" temperature is attained, the vane obscures the light source to the photo-transistor, the relay is de-energised and the switch operates to the "break" position. As the vane passes a "set" point, it continues to obscure the light source until it reaches a stop. This patented feature enables a true indication of temperature to be given up to 20% of full scale deflection above "set" point.

In the case of proportional control instruments, the red control setting pointer is mounted on a separate radial arm, and the control arm carrying the light source, mirror and photo-transistor is made to oscillate

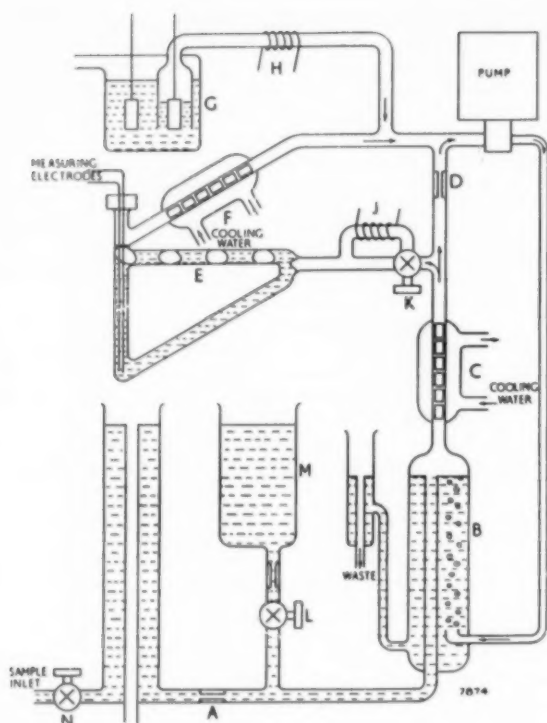


Kelvin & Hughes transistor type indicating controller.

relative to the setting arm by means of a synchronous motor and an eccentric ring drive. The position of the eccentric is governed by friction only and the external setting knob moves the control arm with respect to the setting arm, thus the amplitude of oscillation, i.e. proportional bandwidth, can be adjusted from zero to 10% of full scale. The movement of a red tipped pointer over a small subsidiary scale shows this oscillation. The subsidiary scale is graduated in percentage of full scale, and has a small index pointer which can be adjusted manually to correct for proportional offset.

Dissolved Oxygen Recorder

Modern high temperature and pressure steam systems require dissolved oxygen recorders capable of measuring concentrations of less than 0.01 p.p.m. Such a recorder should have an accurate zero of high stability, a high sensitivity and freedom from leaks. Furthermore, the



Simplified schematic diagram of analyser unit in Cambridge dissolved oxygen recorder.

readings should be specific for oxygen. An electrochemical cell inserted directly in the water flow suffers from the effects of interfering substances, in concentrations so low that they are impossible to identify or measure. In the electrochemical dissolved oxygen recorder shown at Olympia by the Cambridge Instrument Co., Ltd., this disadvantage is overcome by using an indifferent gas—hydrogen—to transfer dissolved oxygen from the feed water into the solution in the cell. Most impurities are non-volatile and thus cannot reach the cell, while the known volatile ones do not affect the measurement.

The outfit consists of an analyser unit, electronic recorder, control panel, mains unit, flow regulator and water cooler. Referring to the accompanying sketch, which is a simplified schematic diagram of the analyser unit, feed water from the cooler is brought to the inlet constant head tower which, in conjunction with the orifice *A* provides a constant flow through the scrubbing tower *B*, and thence to waste. Hydrogen is pumped through the scrubbing tower in a series of small bubbles, leaving the tower via a vapour trap *C* and returning to the pump. A restriction *D* in this circulating system after the vapour trap provides a by-pass flow to the electrochemical measuring cell *E*, through the horizontal limb of which the gas passes in the form of bubbles, leaving the cell via a vapour trap *F* which prevents carry-over of the solution into the gas system. The hydrogen lost in solution in the feed water is replaced by means of an electrolytic cell *G*.

To prevent oxygen being introduced into the system from the electrolytic cell, hydrogen from this source is

passed through a small furnace *H*, where it is brought in contact with a catalyst to remove any traces of oxygen.

Connections from the electrodes in the electrochemical cell are taken to the control panel, which contains the sensitivity and zero adjusting circuits. From the control panel, leads are taken to the recorder.

The furnace *J* is used in checking the instrument zero, the two-way cock *K* being turned to pass the gas from *B* through the furnace so that all trace of oxygen will be removed before it passes through the cell. Checking of the sensitivity is effected by opening stopcock *L* and allowing air-saturated water from the constant head device *M* to enter the sample stream.

To test the analyser for leakage, the inlet cock *N* is closed, trapping a quantity of sample water in the scrubbing tower. The pump continues to circulate hydrogen, and this is passed through the zero-furnace to remove any oxygen and establish the zero. The two-way cock *K* is then turned to by-pass the furnace and circulate the gas. An increase in reading of the recorder would indicate the presence of oxygen, due solely to leakage from the atmosphere. The error due to the leak can be estimated from the recorder indication.

Microfocus X-ray Generator

Intensity of radiation is a most important factor in all X-ray diffraction techniques. When conventional X-ray tubes are used in which the dimensions of the focus are about 10 mm. \times 1 mm., collimation requirements often allow the use of radiation from only a small area in the centre of the focus, the radiation coming from the surrounding area being wasted, and the heat generated in producing this unwanted radiation adding to the problem of cooling the useful central part of the focus. Moreover, the unwanted part of the radiation may be scattered and add to the background. Efforts to increase the intensity of the focus without reducing its size, such as have been made in rotating anode tubes,



Hilger microfocus X-ray generator.

add to the problems of maintenance and require powerful and expensive high tension generators.

The X-ray generator shown by Hilger & Watts, Ltd., at Olympia, has a focal area of 0.1×1.4 mm., and operates with perfect safety with a copper target at a power of 150 W.; this gives an average intensity equal to that obtained by the dissipation of 10 kW. on a 1 mm. \times 10 mm. line focus. A power of 200 W. may be used for several hours without undue roughening of the target. The brilliance is thus many times greater than with a conventional tube, and, in consequence, exposure times are often considerably reduced; in addition, the total power is adequate for the majority of X-ray diffraction problems. As an alternative, the generator can be fitted with a microfocus gun giving a focus of 40μ in diameter. In this form, it operates at only 25 W. on a copper target, and, although not powerful enough to take the place of more conventional tubes, is indispensable in a number of special applications in X-ray diffraction and micro-radiography.

The exceptionally clear working space on the table top all round the tube offers the minimum of obstruction to all types of accessory equipment. By appropriately choosing one of two versions of the tube and of the cathode gun, horizontal or vertical line foci or circular foci are obtainable, thus making the generator extremely versatile in application.

High Intensity Microscope Illumination

The high pressure mercury vapour lamp has long been favoured by metallurgists who find its very high intensity a very necessary feature in microscope systems where "light-efficiency" is seriously reduced by partial

now find that they, too, require the brightest possible light sources. Much photomicrography of rapidly moving living material is also being undertaken and in order to achieve short exposure times, the mercury vapour lamp becomes essential.

It is to satisfy these, and other, specialised requirements that the Duplex version of the No. 50 Universal microscope shown at the Physical Society Exhibition by R. & J. Beck, Ltd., has been introduced. The general appearance can be seen in the accompanying illustration. Fundamentally, an enlarged base-plate with two lamp-house pillars is provided, along with a periscope fitting to fit into the base of the microscope. Either one or two mercury vapour lamps, with their associated condenser lenses and filter racks, can be provided. If two are fitted, it is possible to obtain mixed transparent and opaque illumination of the specimen of a brilliancy never before achieved. The necessary control gear (a choke and condenser) per lamp is either built into the microscope table or supplied housed in a steel cabinet as a "power pack" unit.

Thickness Gauges

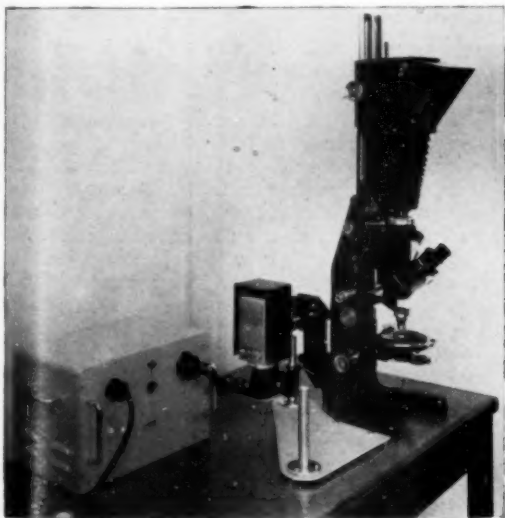
Baldwin Instrument Co., Ltd., have developed in recent years a range of instruments for measuring the thickness of material, particularly strip, without contact. They are dependent on the absorption of radiation by the material, and models are available which are suitable for a wide range of materials and thicknesses. The beta ray gauge has found widespread application, but in the case of steel strip, the top limit of measurement is 0.020 in., with equivalent thicknesses in other metals. Above this there is a considerable gap before the gamma ray sources can be used, the gap extending from 0.020 in. to 0.250 in. in the case of steel. This is an extremely important thickness range for many rolling mills, and it is fortunate that, by applying a beta-emitting radioactive source in a novel manner, a nucleonic gauge utilising the resultant "bremsstrahlung" radiation has been evolved, which can be used for the measurement of steel thicknesses in the 0.020-0.250 in. gap, and can, in fact, be so arranged as to measure even lighter gauge material.

By adding a further deck to the control cabinet, the equipment can be arranged to standardise itself automatically. To enable this to be done, a special C bracket has been designed to hold the measuring head in position with respect to the material being measured. As the automatic standardising procedure comes into effect, the measuring head is automatically withdrawn by means of a pneumatic power cylinder. A standard feature of the Baldwin Atomat gauges is a test meter which is connected by means of a rotary switch to the salient parts of the circuit to check for faults.

Whilst not exactly a thickness gauge, the nucleonic level indicator shown by Baldwin Instrument uses the same principle. Radiation from a radioactive source at one side of the container is picked up by a detector at the other, the latter being designed to discriminate between the different intensities of radiation received when material in the container does or does not cut the beam of rays. As will be appreciated, no fittings are necessary inside the container.

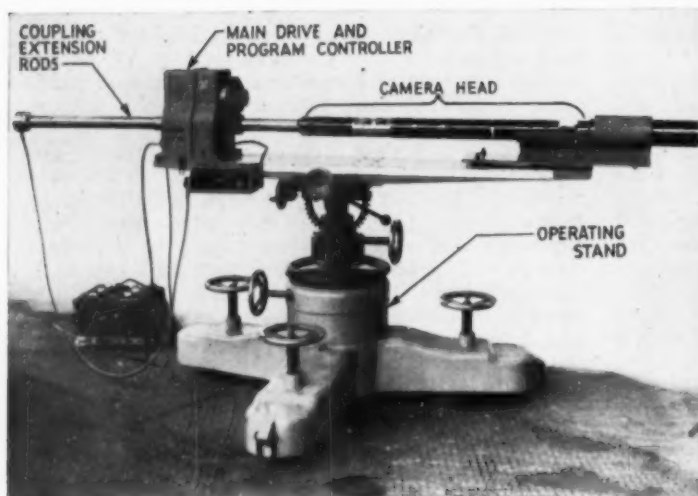
Photography of Internal Surfaces of Long Tubes

A semi-automatic camera designed to provide a composite photograph representing the developed surface



Duplex version of the Beck No. 50 Universal microscope.

reflectors in the illuminating beam. This, coupled to the relatively low transmission of efficient polaroid materials, has caused the metallurgist to seek the brightest possible light sources. For transparent materials, this has not been so essential, but with the increasing interest in the use of polarising, phase contrast and dark-field techniques applied to biological materials, such workers



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Camera for photographing bore surfaces.

of the bore of 30 ft. tubes of diameter 3 in. and over, at approximately full size, was shown at the Physical Society Exhibition by the Ministry of Supply's Armament Research and Development Department. A scanning system is employed and the image is recorded on 35 mm. film (70 mm. film for tubes over 5.5 in. diameter) continuously moving behind a slit at the image plane. The tube is scanned in parallel circumferential sections, each ring being 24 mm. wide. After one ring has been photographed the camera is advanced one picture width. Interchangeable heads are provided covering the range from 3 to 6.4 in. diameter.

The cylindrical camera body which passes through the tube being photographed consists of two parts. The forward portion contains the illumination and optics and the rear portion the film. The two parts are connected rigidly together by a short hollow spindle, through which the image passes to the film. Located on this spindle is a freely rotating bevel gear from which the film drive is derived through a clamping device which grips the wall of the tube, and which also holds the camera in a fixed longitudinal position.

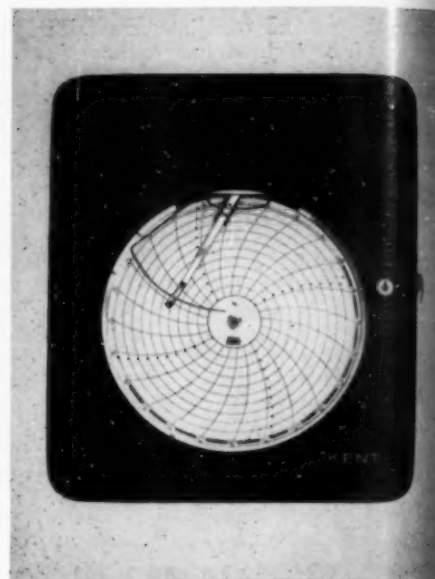
The main rotational drive mechanism is separate from the camera body, and is fitted on a heavy stand which is adjustable in all directions to facilitate alignment. The stand also contains the commutator for automatic switching of the electric circuits and a control panel. The main drive motor is of a synchronous type (230 V. A.C.) but the lamp and electrical equipment in the camera operate from 12 V. D.C.

Extension tubes, each 1 m. long, and housing the electrical connections, are used to connect the camera body to the drive mechanism, and to enable the camera to be rotated and also advanced down the bore.

Electronic Potentiometer Recorder

The introduction of the new Commander KE self-balancing electronic recorder makes the Kent Commander range one of the most versatile in the instrument industry and, by embracing a whole new field of measurements, enables users to find a standard Commander unit to meet their requirements.

Among the many advantages claimed for the KE are: all-mains operation—no batteries—with continuous



Kent KE electronic controller.

standardising; fast and continuous self-balancing by electronic amplifier and servo-motor; automatic cold-junction temperature compensation for thermocouple measurements; inter-changeability with other Commander instruments of auxiliary units (control, integrator, etc.); robust mechanical design of balancing system; all balancing mechanism, etc., at rear, leaving the front accessible for those units which the user needs to reach easily for routine setting up and adjustment; upscale/downscale drive in the event of failure as a built-in feature; linear scale provided on thermocouple ranges; ease of maintenance—plug-and-socket connections for amplifier, reference unit, motor (with tachogenerator) and converter.

The KE offers indicating, recording and controlling functions, and employs the null-balance principle of operation, whereby the voltage derived from the slide-wire (reference potential) is compared with the measured potential, the resulting error signal being fed into an amplifier, where it is converted to a mains-frequency A.C. by a synchronous converter and then amplified electronically. The output is fed to the control windings of a servo-motor which drives the pen and rotates the slidewire contacts until the error signal is again zero, when balance is obtained.

Correction

OCCURRENCE OF THE BETA-MANGANESE STRUCTURE IN TRANSITION METAL ALLOYS AND SOME OBSERVATIONS ON CHI-PHASE EQUILIBRIA.

We regret that, although the weight percentage figures given below Table I on page 18 of the July 1957 issue are correct, a number of errors appear in the atom-percentage figures. The correct details are as follows.

* Composition			Fe	Cr	W	C
			Wt.-%	Wt.-%	Wt.-%	Wt.-%
Alloy I	Wt.-%		26.4	48.4	24.4	0.80
	At.-%		29.0	58.5	8.5	4.0
Alloy II	Wt.-%		40.3	35.2	23.6	0.87
	At.-%		44.5	43.0	8.0	4.5
Alloy III	Wt.-%		65.6	7.3	26.1	0.95
	At.-%		76.5	9.2	9.2	5.0

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0-85
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